CERES Ed3 Cloud Algorithm Update

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S. Gibson (graphics), G. Hong (nite tau), E. Heckert (web, IG),
M. Khaiyer (val), R. Palikonda (offline testing), R. Smith (web, NPP),
D. Spangenberg (polar), Y. Yi (thickness), C. Yost (phase)

SSAI

P. W. Heck (guts o' retrieval algo)

CIMSS, U. Wisconsin

CERES STM April 27-29, 2010

CERES Ed3 Cloud Mask Changes since Nov 2009 STM

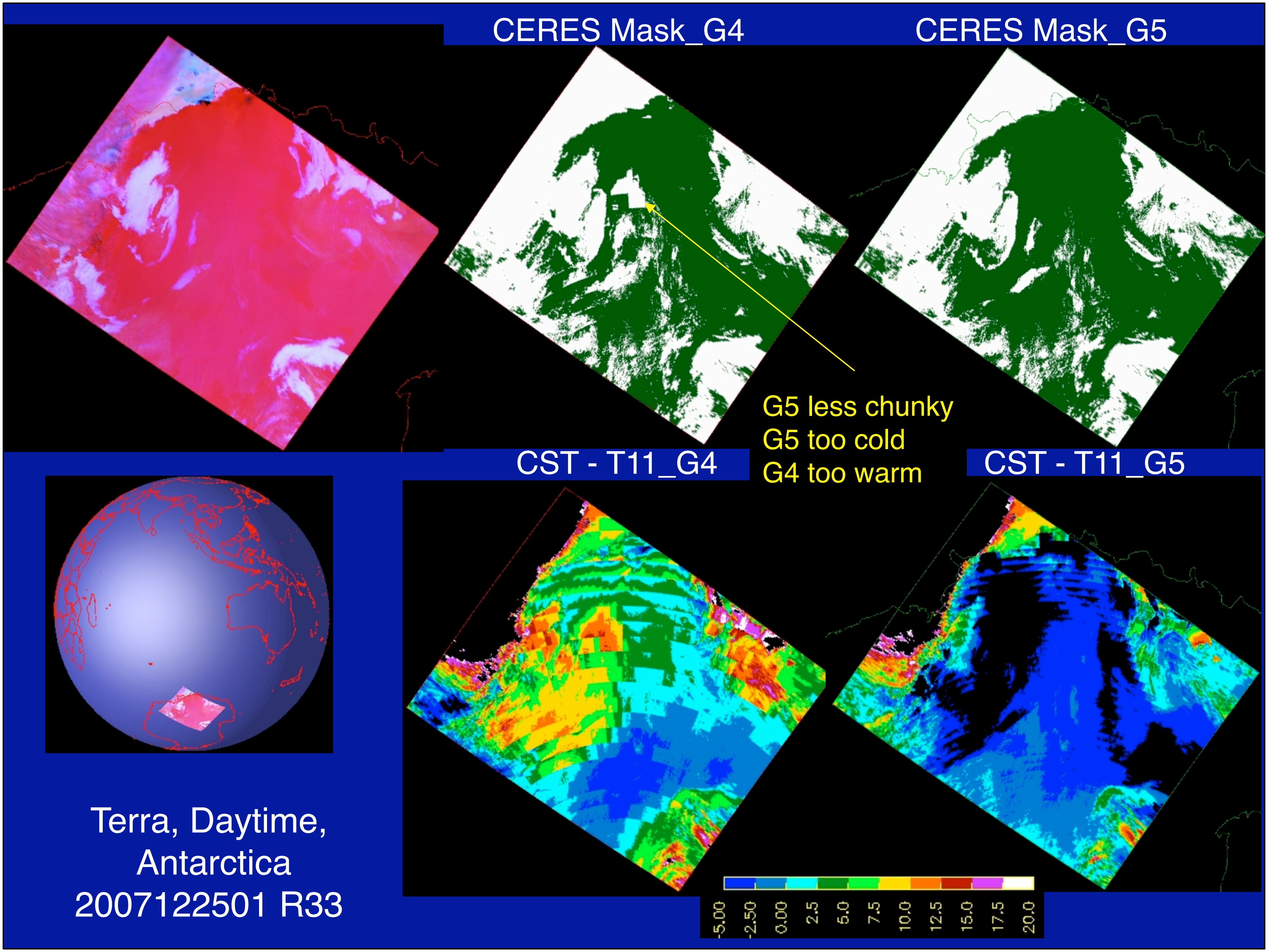
Highlights:

1. Re-adjusted Terra 3.75 μm brightness temperature calibration, especially at low temperature end, affects mostly nighttime Antarctica and Greenland.

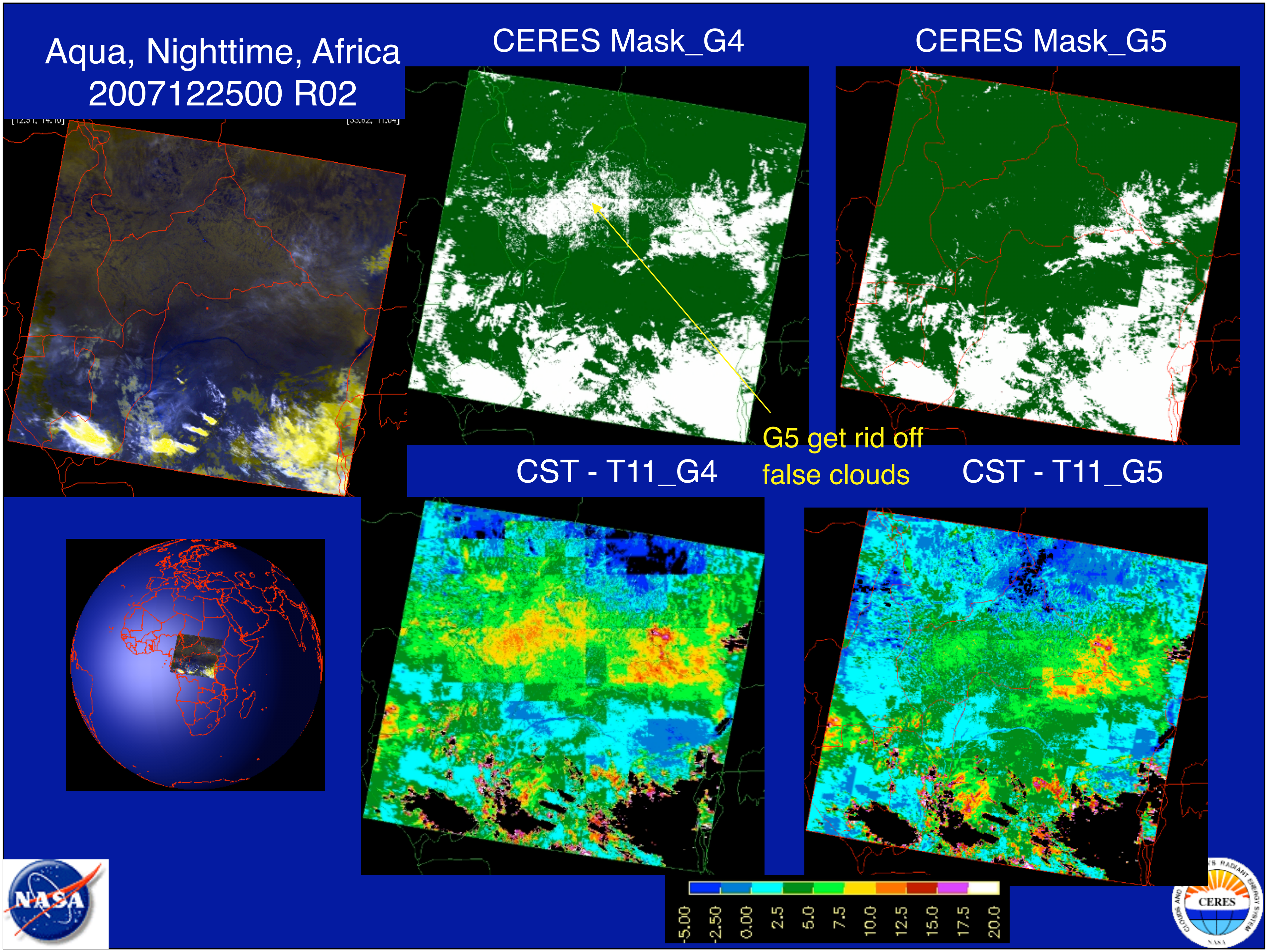
2. Retuned thresholds to compensate for over-prediction of clear sky 11-μm temperature
   - Reduced false clouds over nighttime mid-latitudes to polar transition areas.
   - Reduced chunky false clouds along coasts with dust in glint (Bao Hai Bay, China).

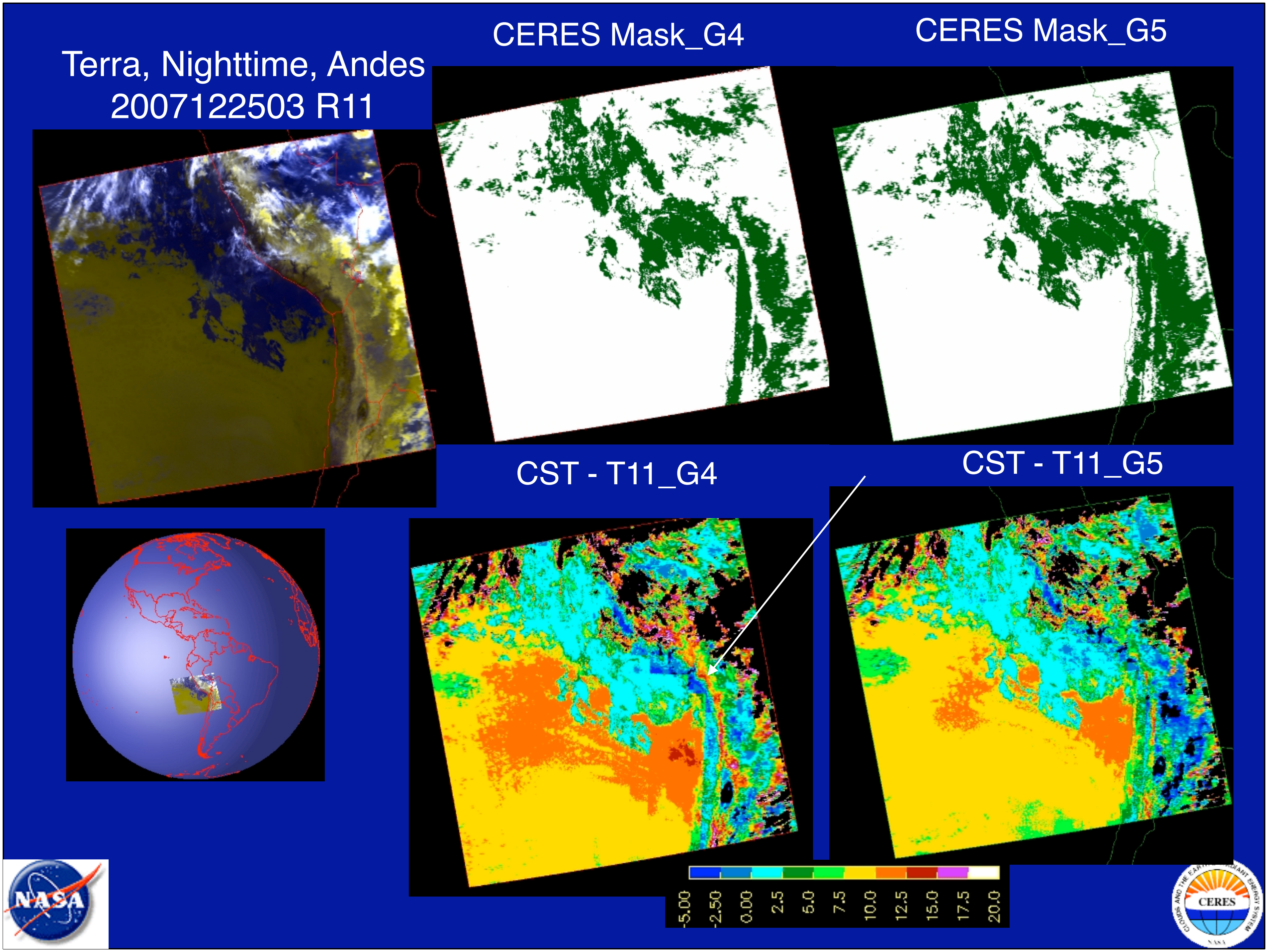
3. Examined impact of replacing GEOS4 MOA with G5-Edition3 MOA to CERES Ed3 cloud mask

Impact of GEOS4 MOA and G5-Edition3 MOA
to CERES Ed3 cloud mask



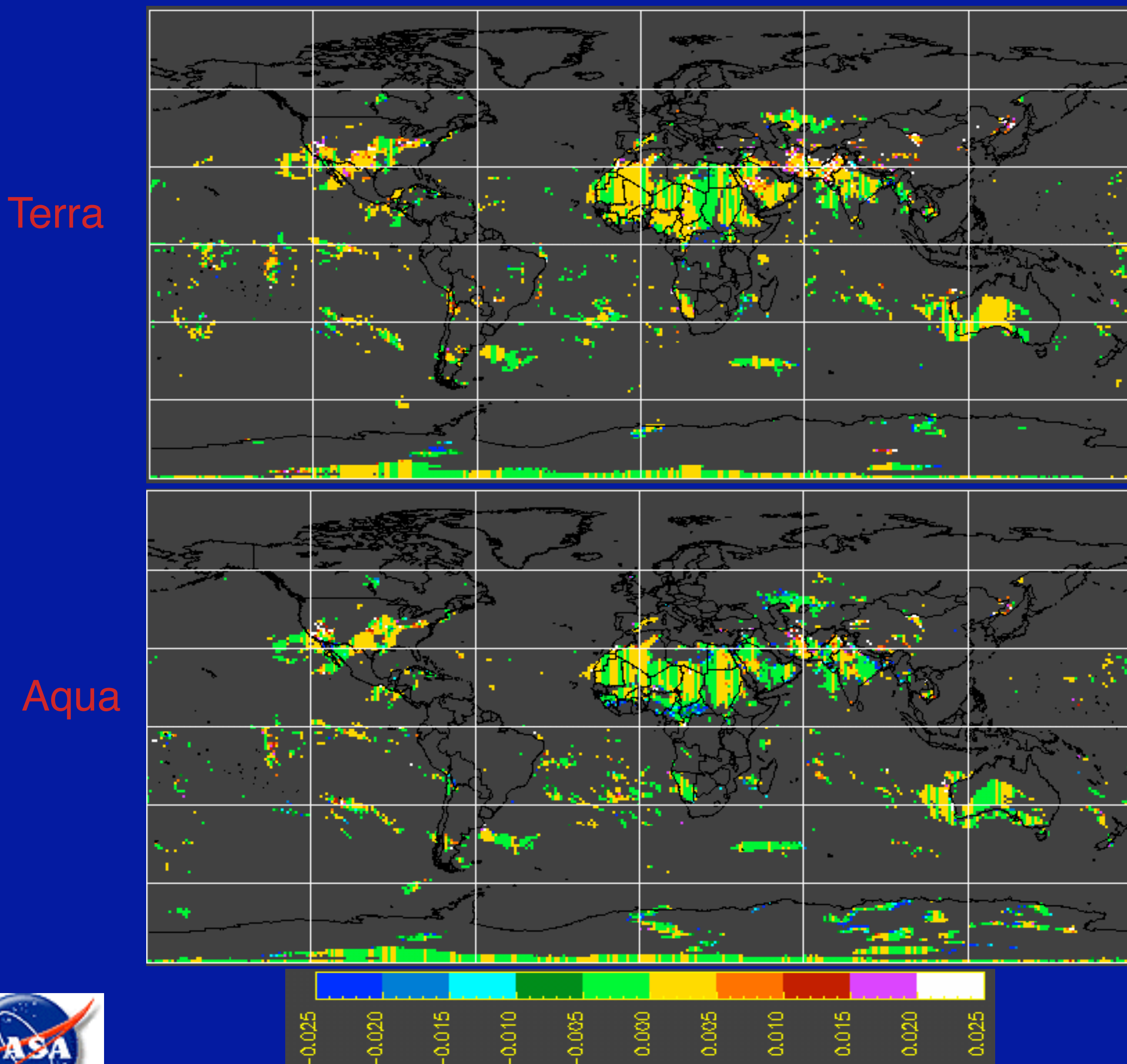
CERES Mask_G4
CERES Mask_G5
G5 less chunky
G5 too cold
G4 too warm
CST - T11_G4
CST - T11_G5
Terra, Daytime,
Antarctica
2007122501 R33
-5.00
-2.50
0.00
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0


Aqua, Nighttime, Africa
2007122500 R02
CERES Mask_G4
CERES Mask_G5
G5 get rid off
false clouds
CST - T11_G4
CST - T11_G5
-5.00
-2.50
0.00
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0


Terra, Nighttime, Andes
2007122503 R11
CERES Mask_G4
CERES Mask_G5
CST - T11_G4
CST - T11_G5
-5.00
-2.50
0.00
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0

Cloud Fraction Differences,G5(Ed3) - GEOS4

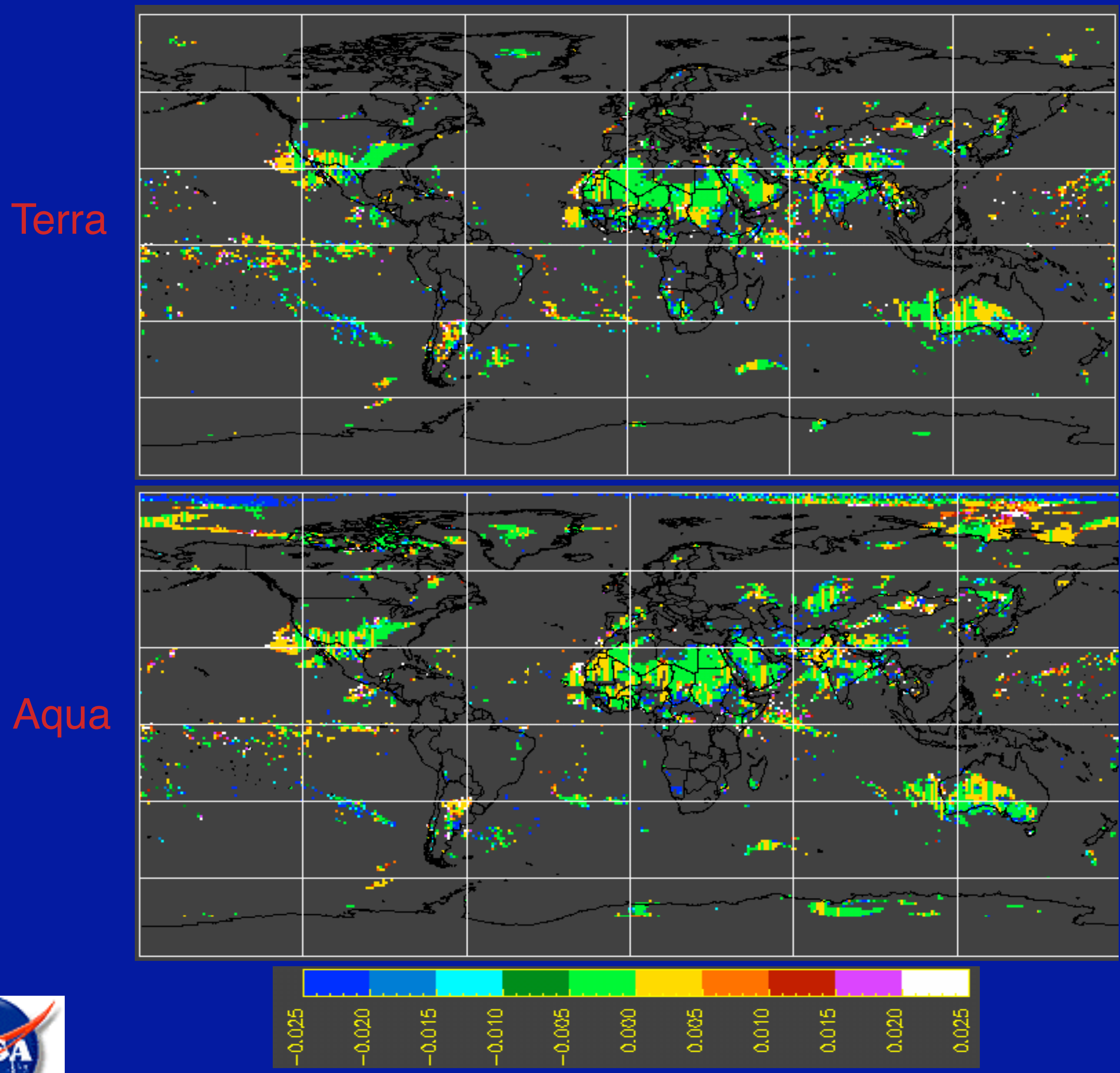
Daytime, 20071225



- Slight increases in cloud cover over land and ocean.
- Few negative changes

Cloud Fraction Differences, G5(Ed3) - GEOS4

Nighttime, 20071225

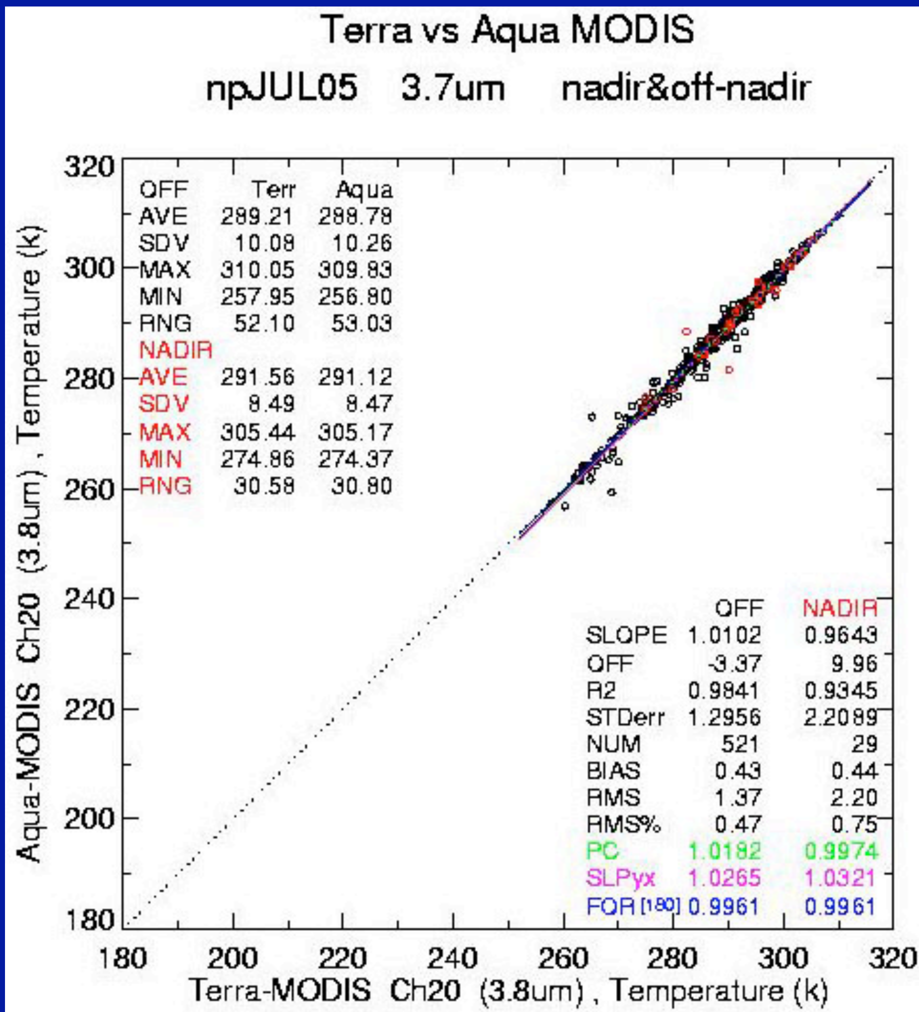


- Slight increases in cloud cover over land.
- Changes both ways over ocean.
- More for Aqua than Terra.

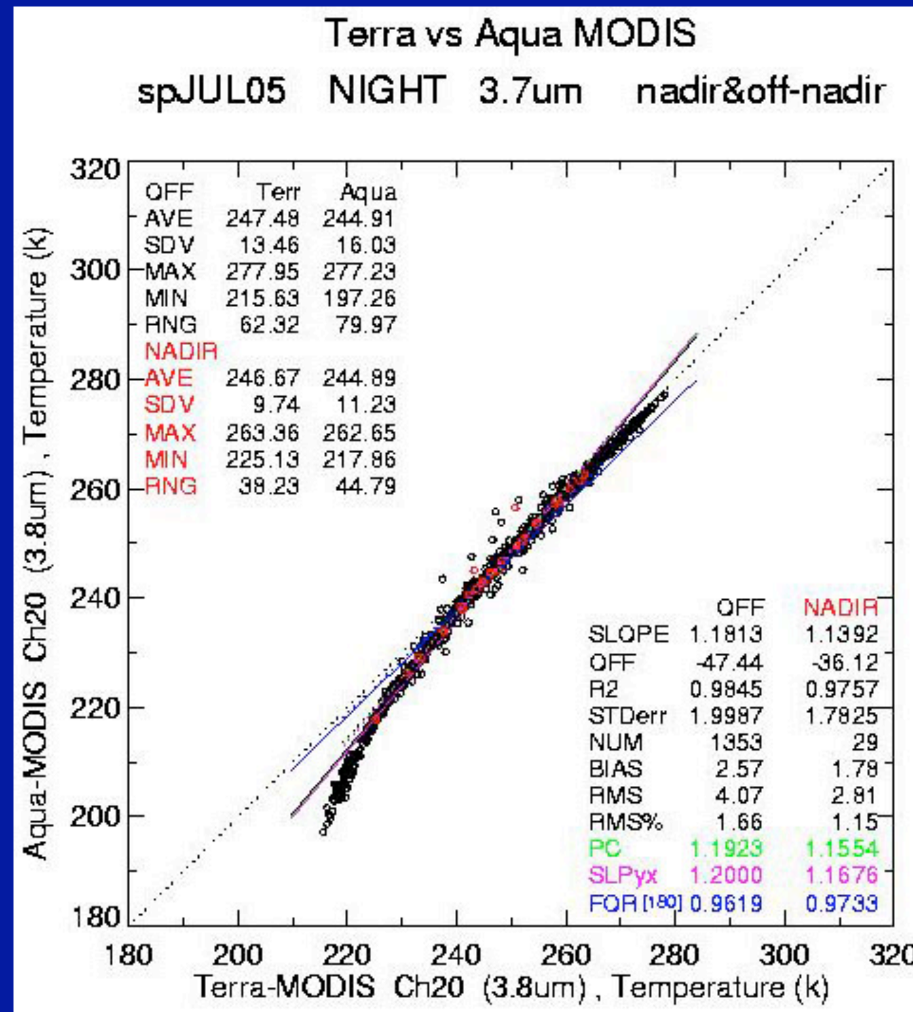
MODIS Correction of V5 Terra and Aqua
3.75 μm by Cross-Calibration

Solar Infrared Channels

Daytime slope



Night slope



- **Aqua 0.57 K warmer than Terra during daytime**
- **Nonlinear difference at night at low temperatures**

Collection 5 Changes 3.8-µm CHANNEL

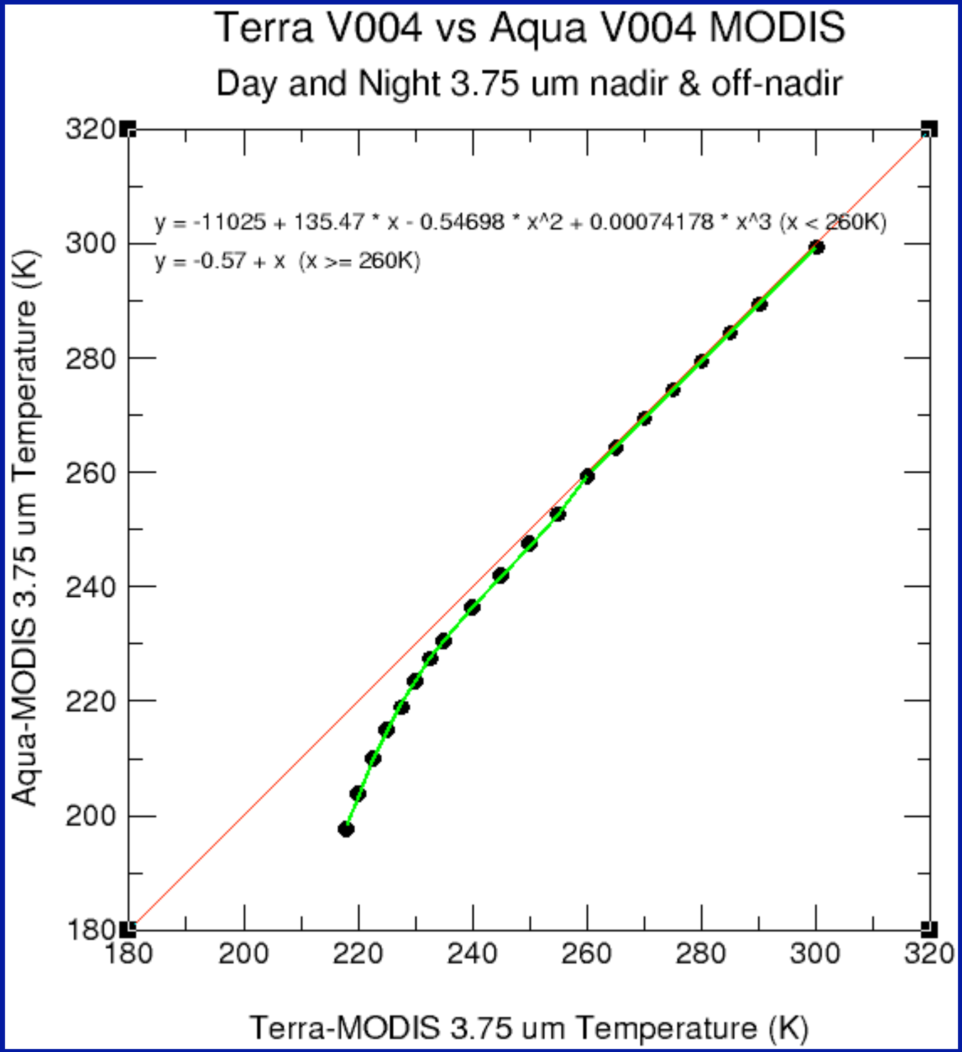
Collection 5-4 Difference

- Collection 5 reduces some of night difference,

  not daytime 0.5 bias

- Difference much greater at low temperatures

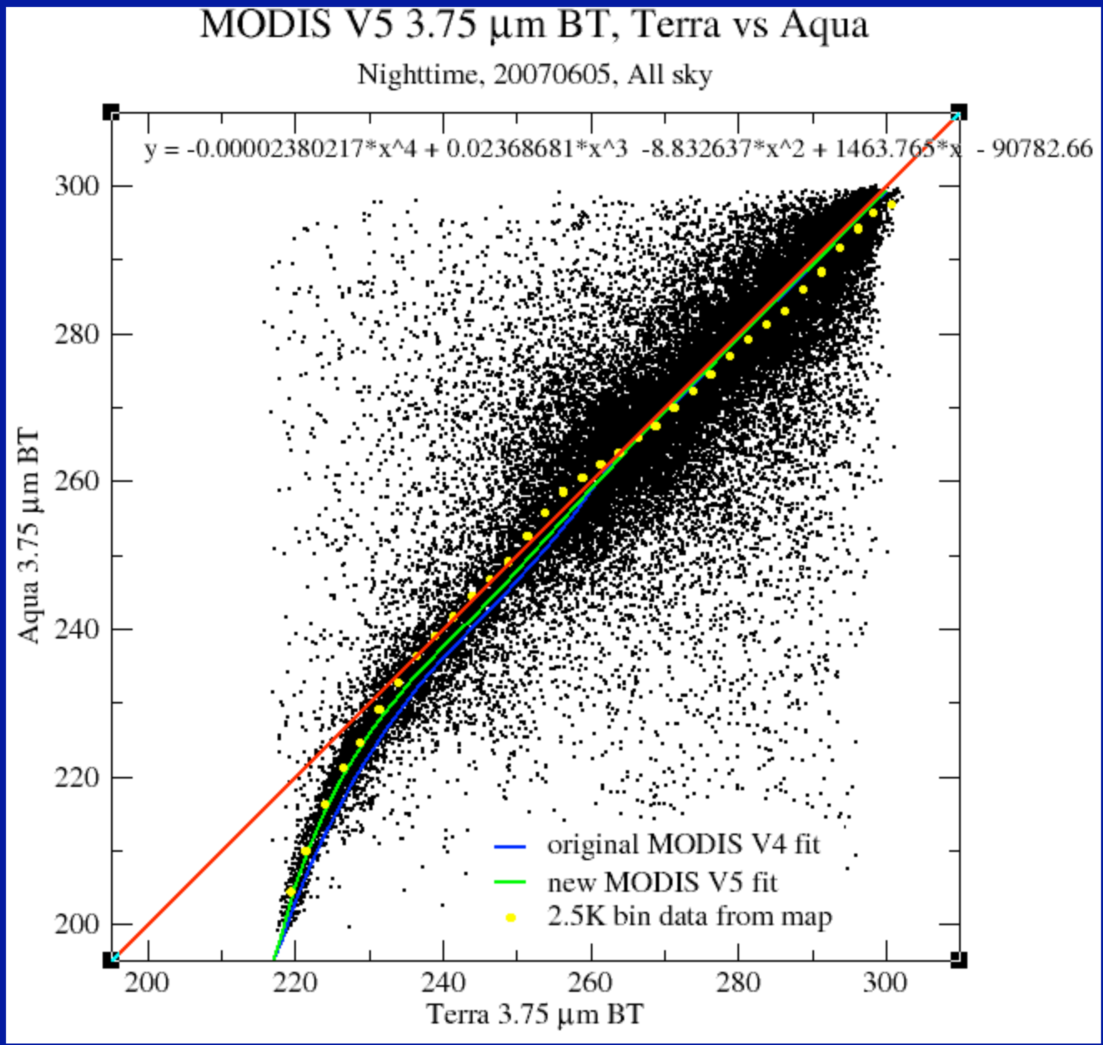
Proposed V4 Terra 3.8-μm Calibration Change



- Captures differences with Aqua and VIRS
- Might be time dependent
- Will increase daytime re by 0.5 -1 µm
- Will require normalization to Collection 5 data

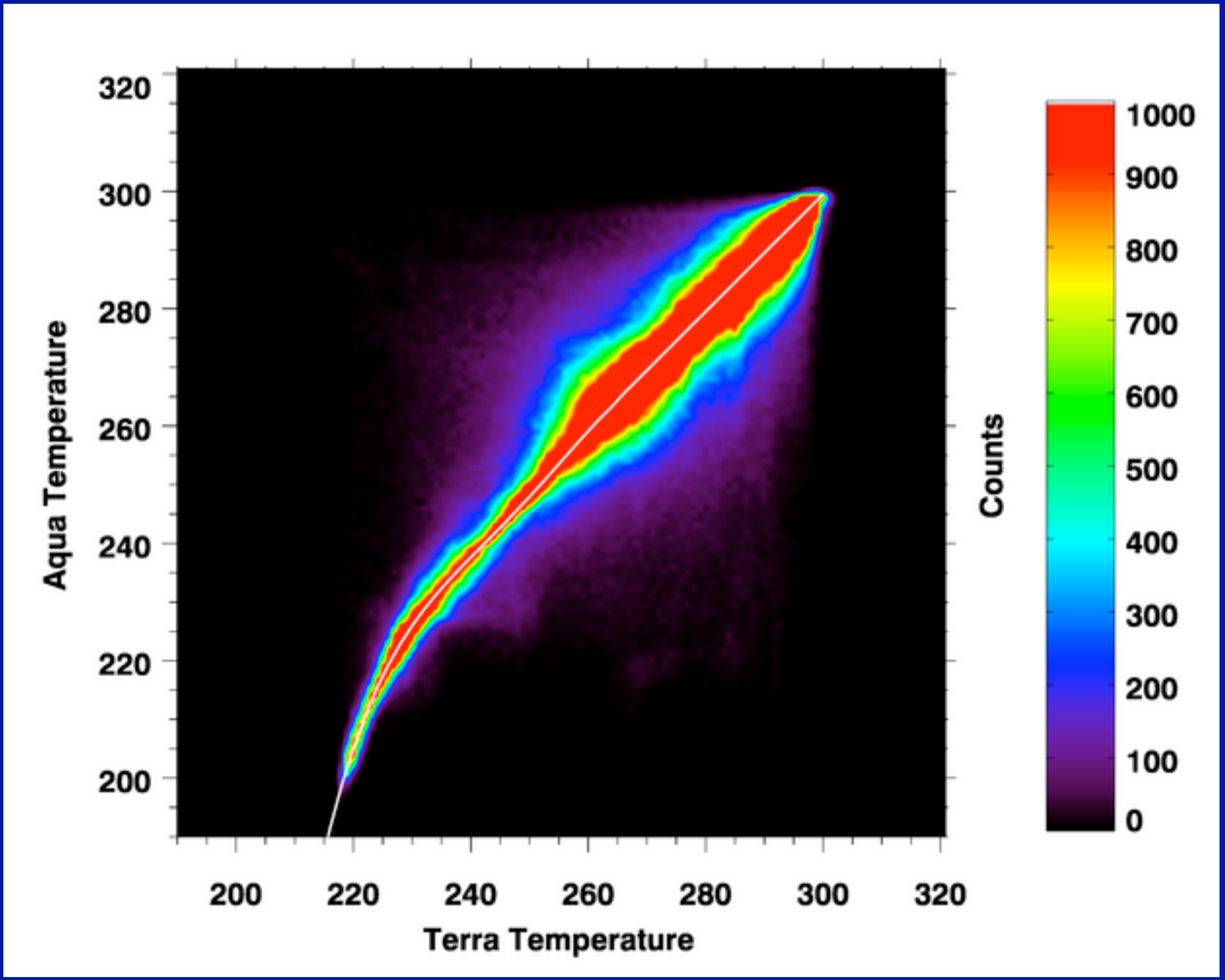
Spatially Matched Aqua and Terra V5 Data, 5 June 2005

- 10' averages
- sample every 50 points



New fit to slightly to left of V4 fit from ray-matched data

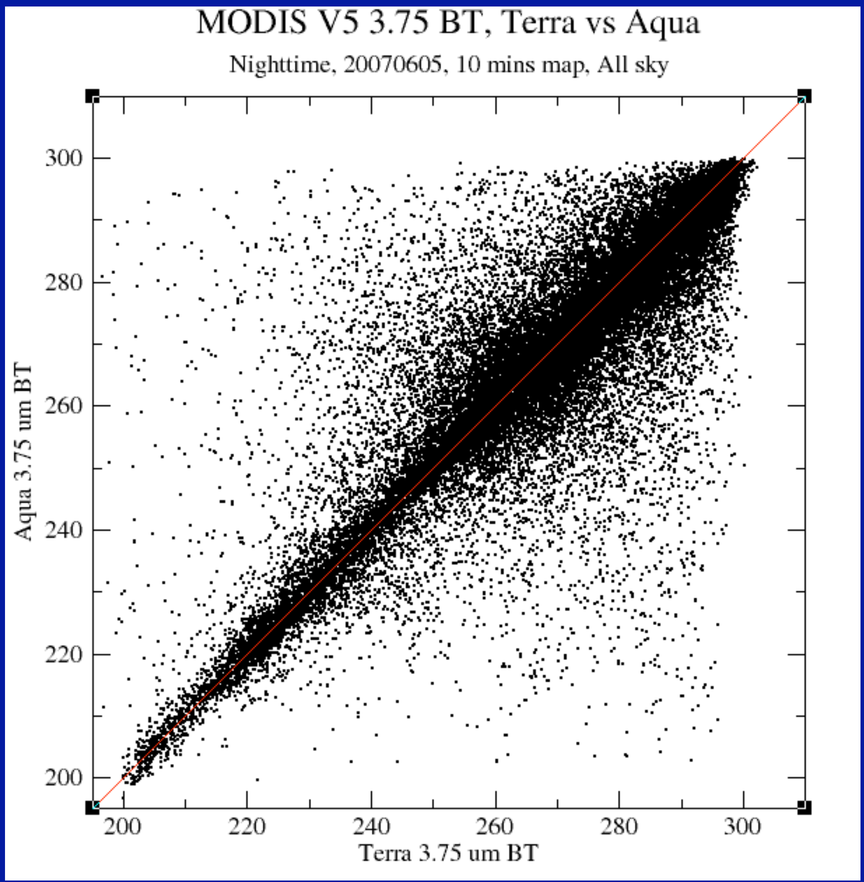
MODIS V5 3.75 μm BT, Terra vs Aqua, Denisty Plot
Nighttime, 20070605, all sky



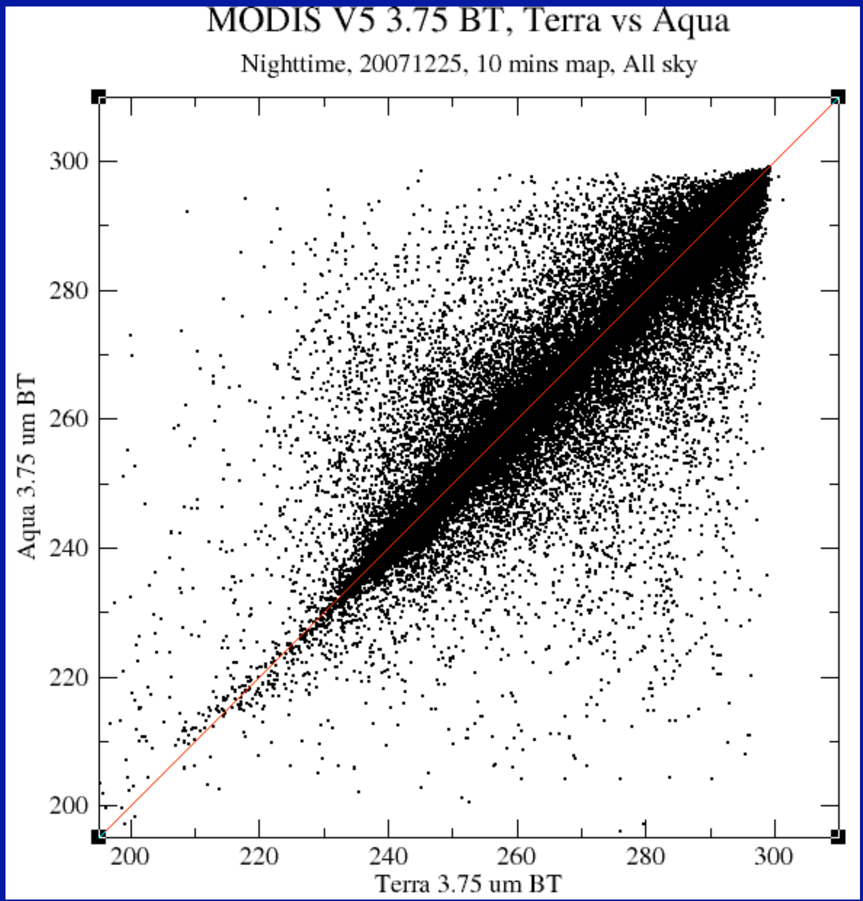
MODIS V5 3.75 μm BT, Terra vs Aqua

After New Correction

20070605



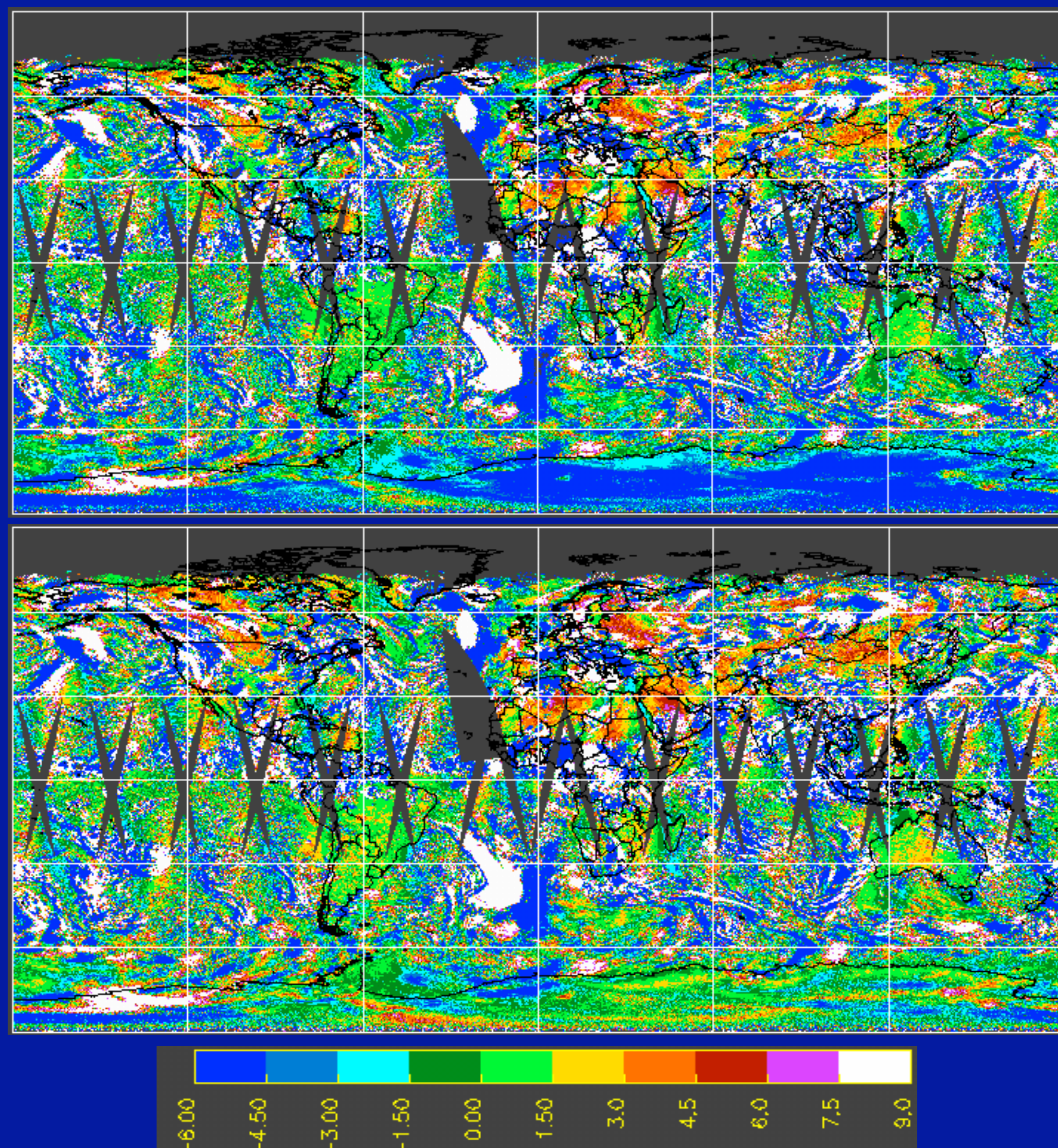
20071225



MODIS 3.75 μm BT Differences between Terra and Aqua
Nighttime, 20070605

Terra - Aqua
Ed3β2 old
correction

Terra - Aqua
Ed3 new
correction

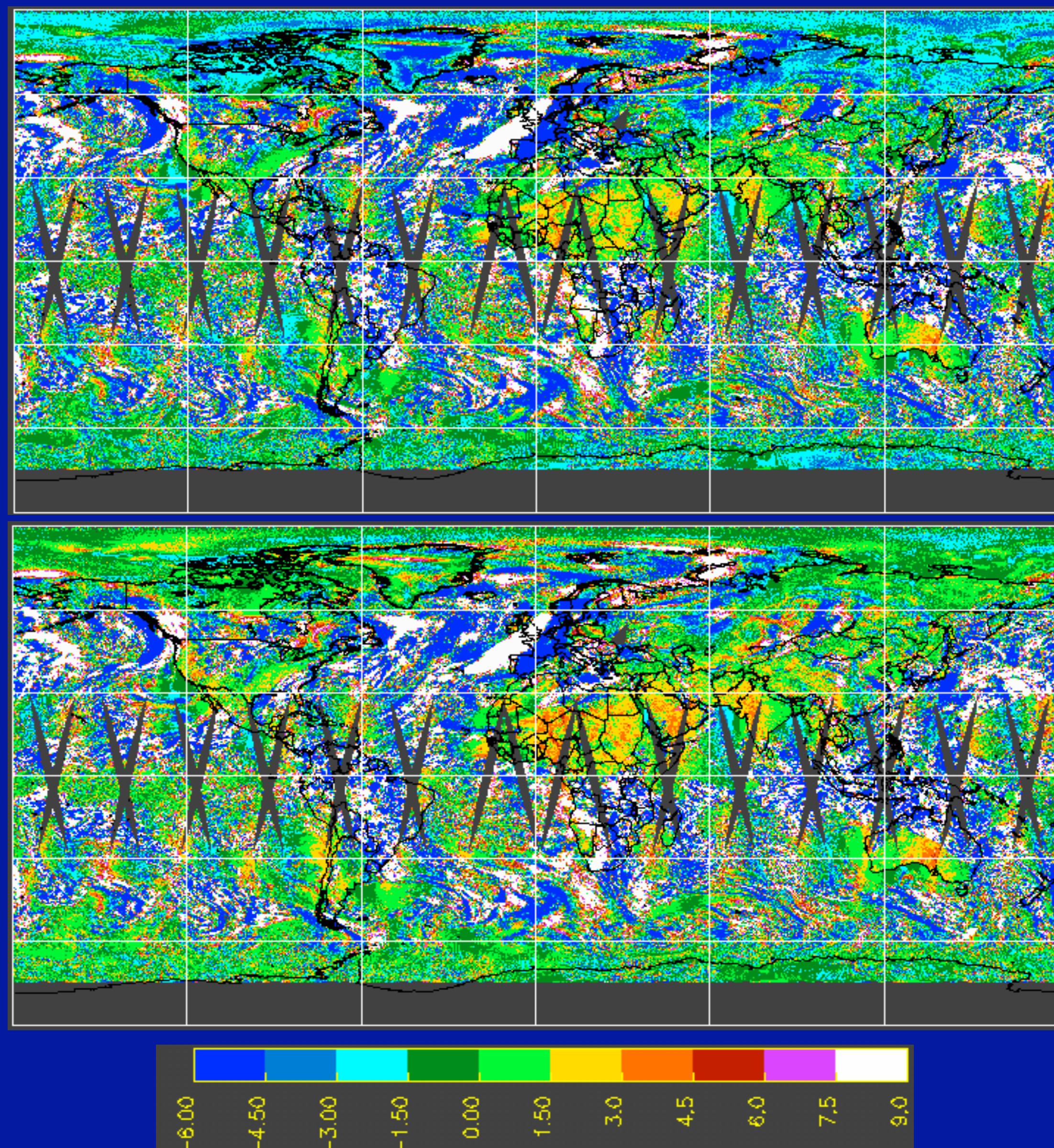


Over Antarctica
Ed3 Terra 3.75 μm
calibrated closer
to Aqua,

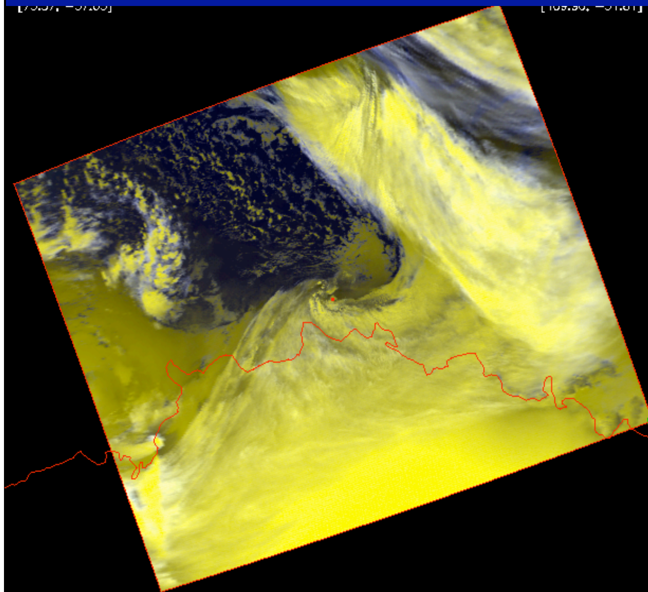
MODIS 3.75 μm BT Differences between Terra and Aqua
Nighttime, 20071225

Terra - Aqua
Ed3β2 old
correction

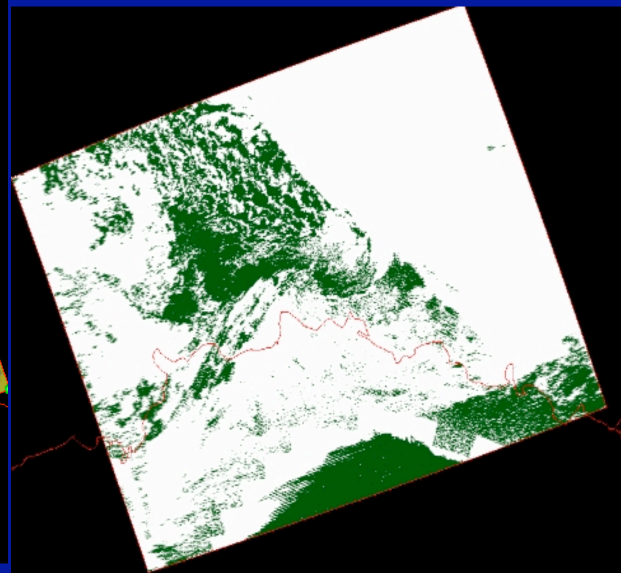
Terra - Aqua
Ed3 new
correction



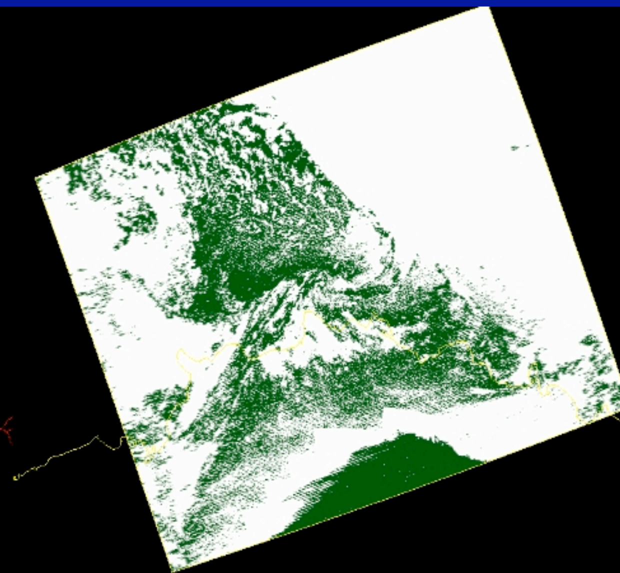
Over Greenland and Arctic sea ice, Ed3 Terra 3.75 μm calibrated closer to Aqua.



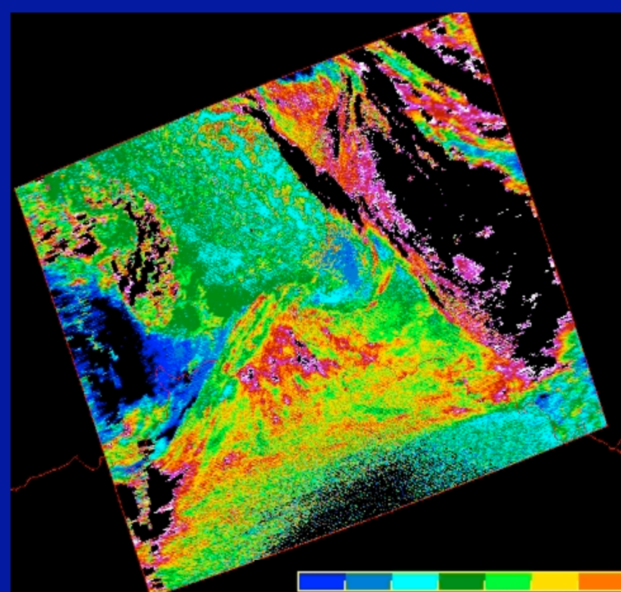
CERES Mask_new curve



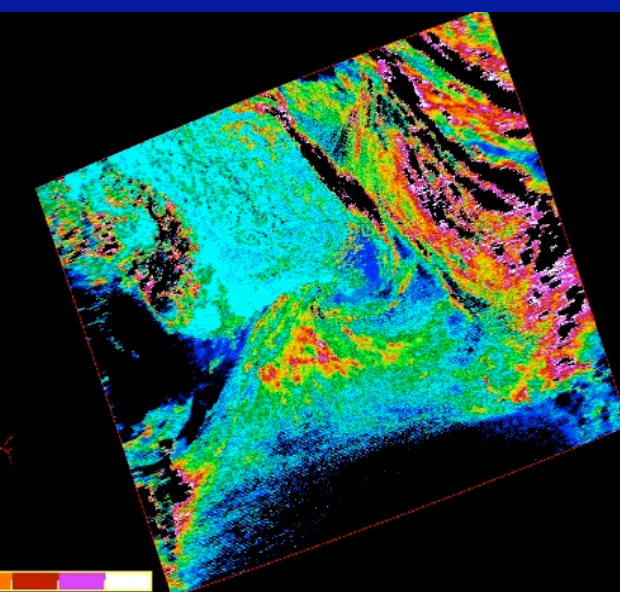
CERES Mask_old curve

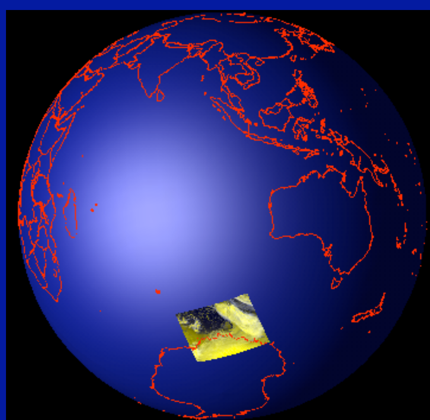


T37-T11_new curve

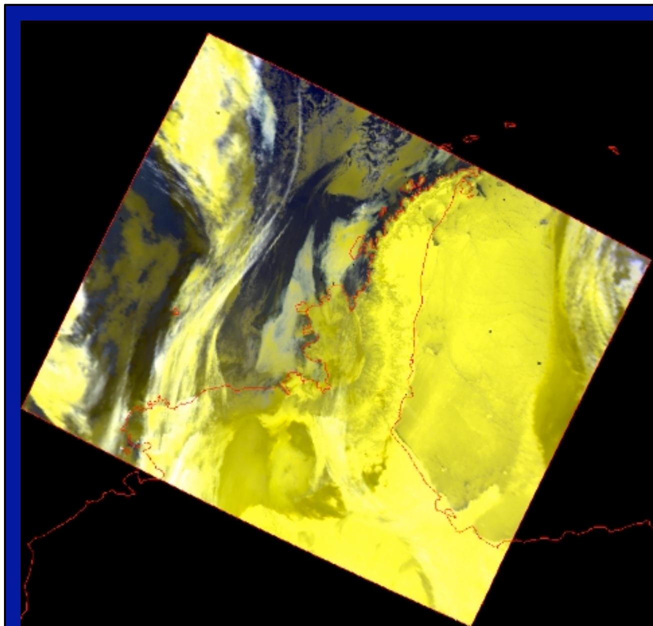


T37 - T11_old curve

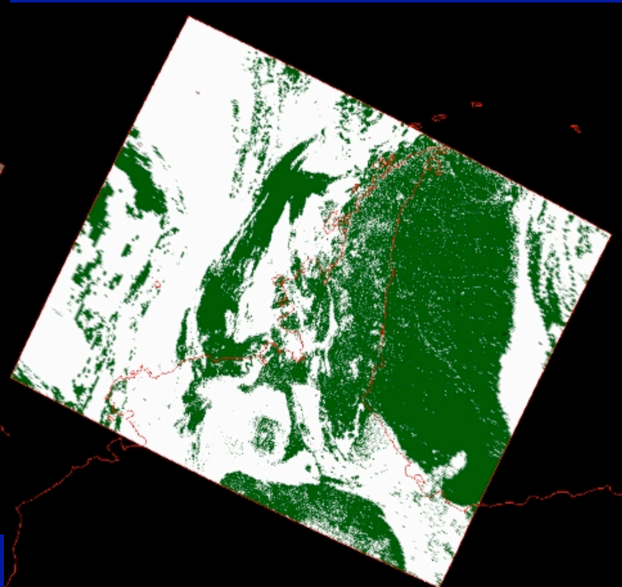




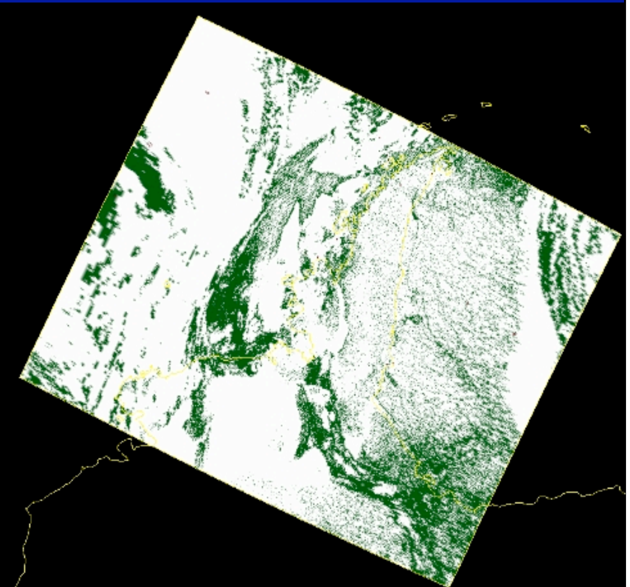
Terra, Nighttime,
Antarctica
2007060517



CERES Mask_new curve

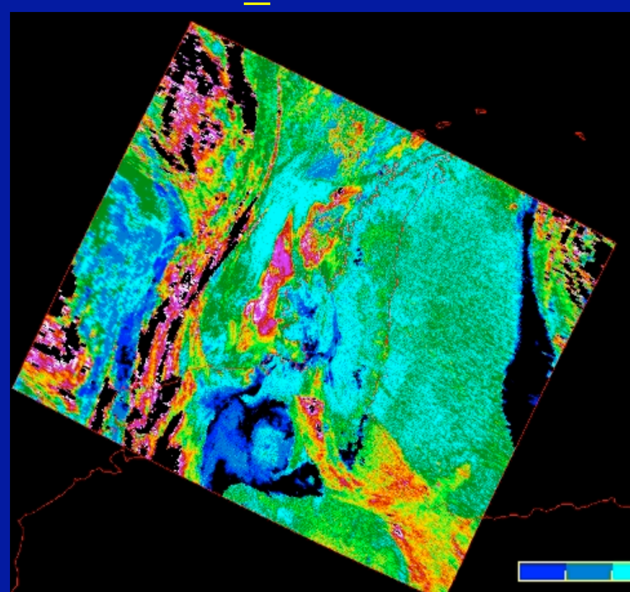


CERES Mask_old curve

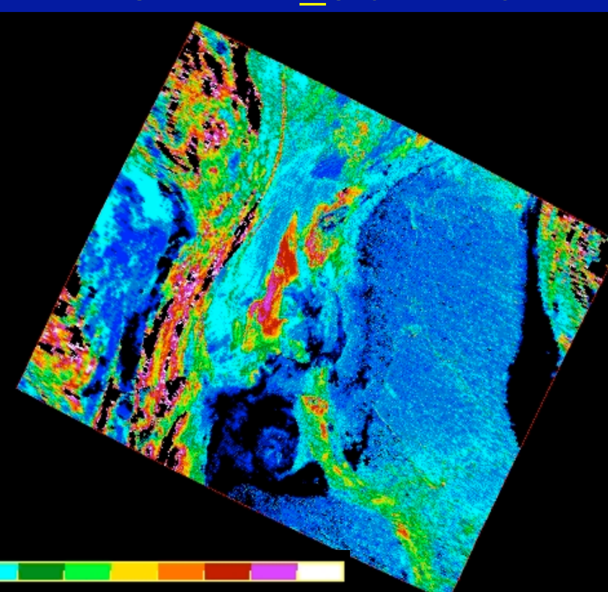


Terra, Nighttime,
Antarctica
2007060513

T37-T11_new curve



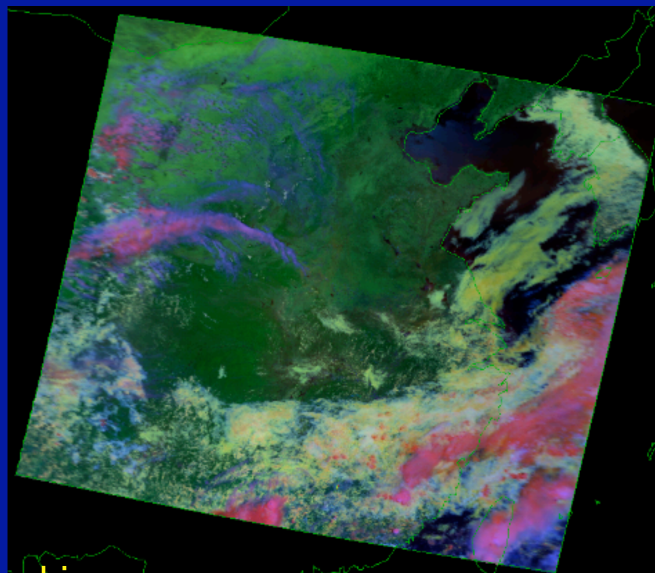
T37 - T11_old curve



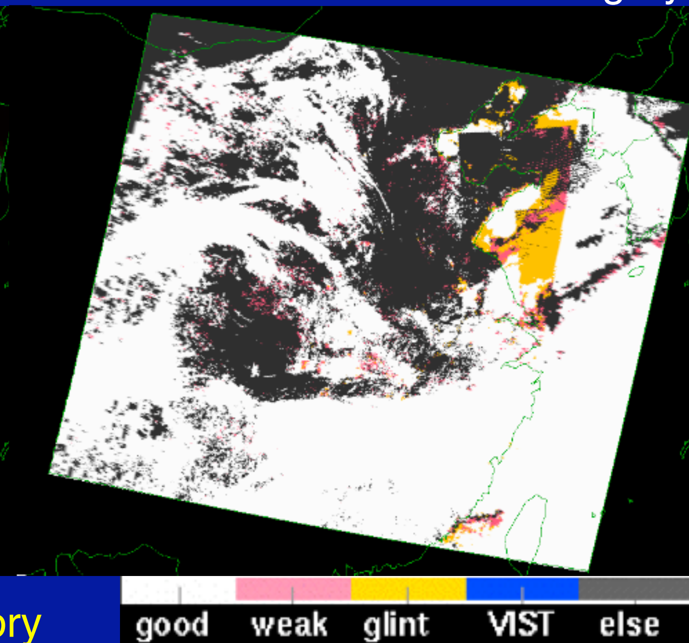
Retuned thresholds in
CERES Ed3 Cloud Mask

Terra, 20070605
03R60
Northeast China
Bo Hai Bay

RGB

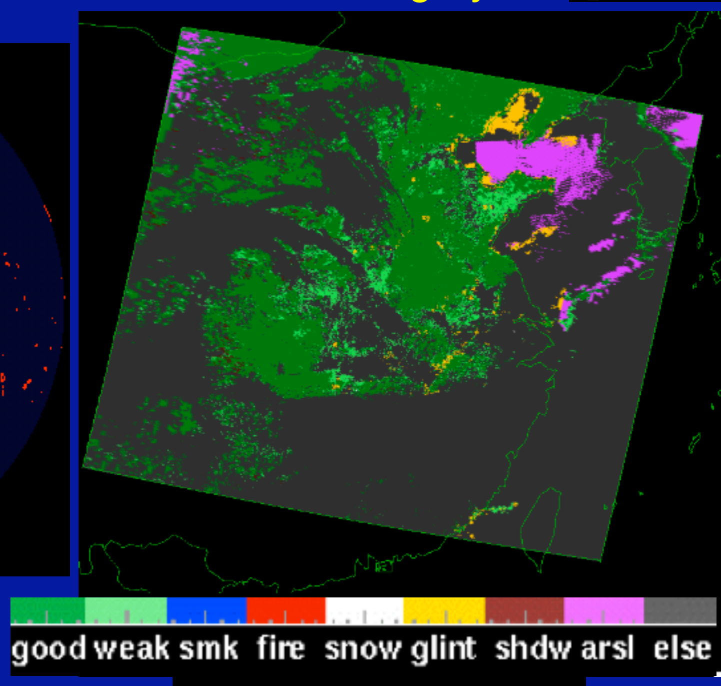


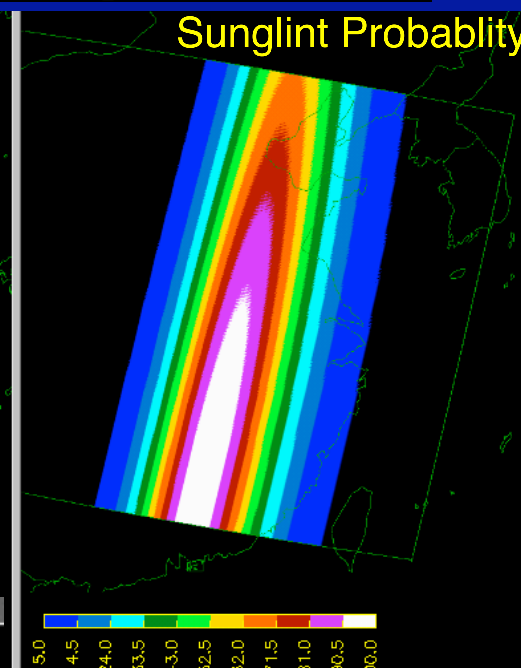
CERES Cloud Category

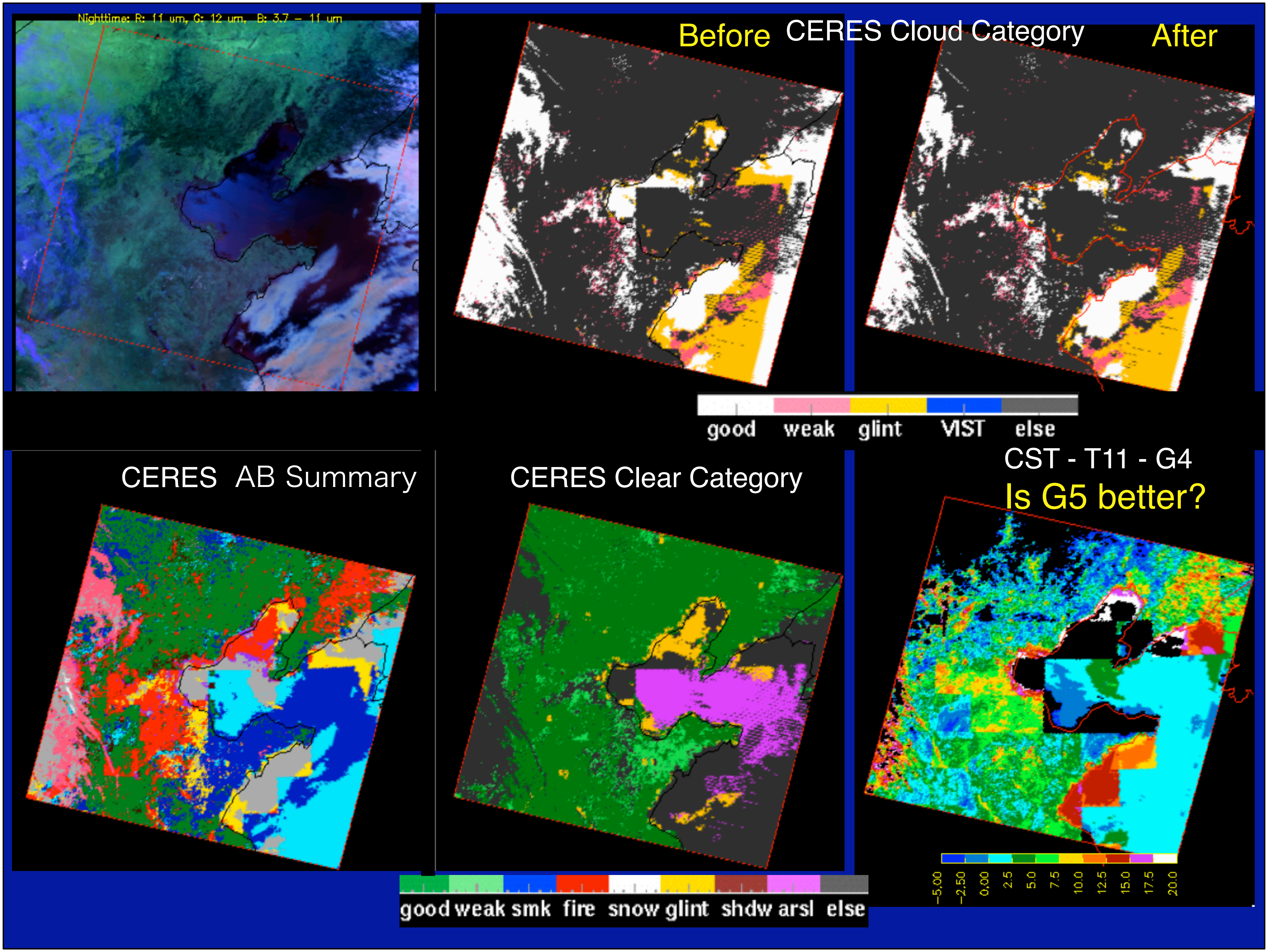


Sunglint, aerosol, and coast, all mixed in

CERES Clear Category

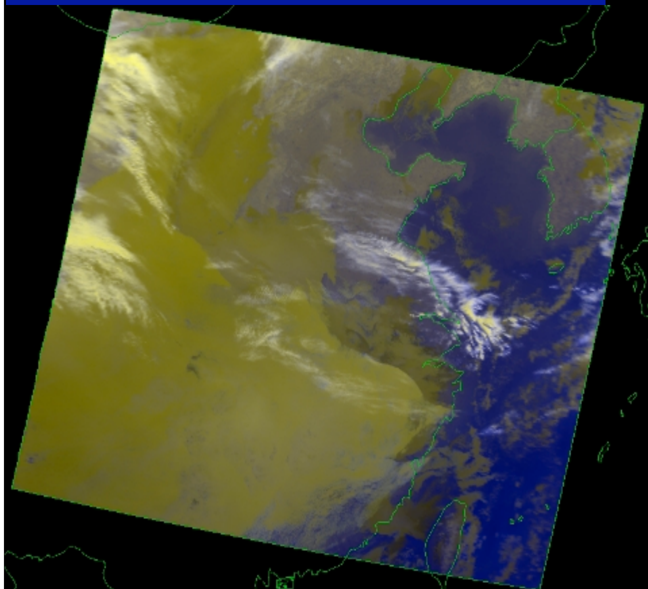




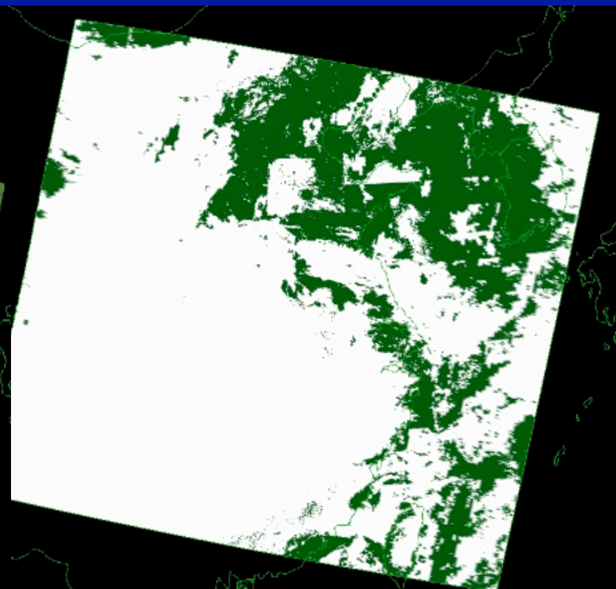


Nighttime: R: 11 um, G: 12 um, B: 3.7 – 11 um
Before
CERES Cloud Category
After
good
weak
glint
VIST
else
CERES AB Summary
CERES Clear Category
CST - T11 - G4
Is G5 better?
-5.00
-2.50
0.00
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
good weak smk fire snow glint shdw arsl else

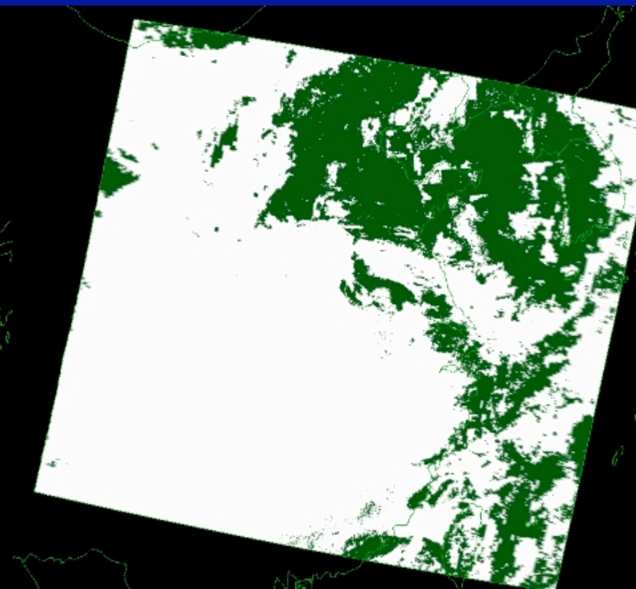
Aqua, Nighttime, China
2007060518



CERES Mask_G4

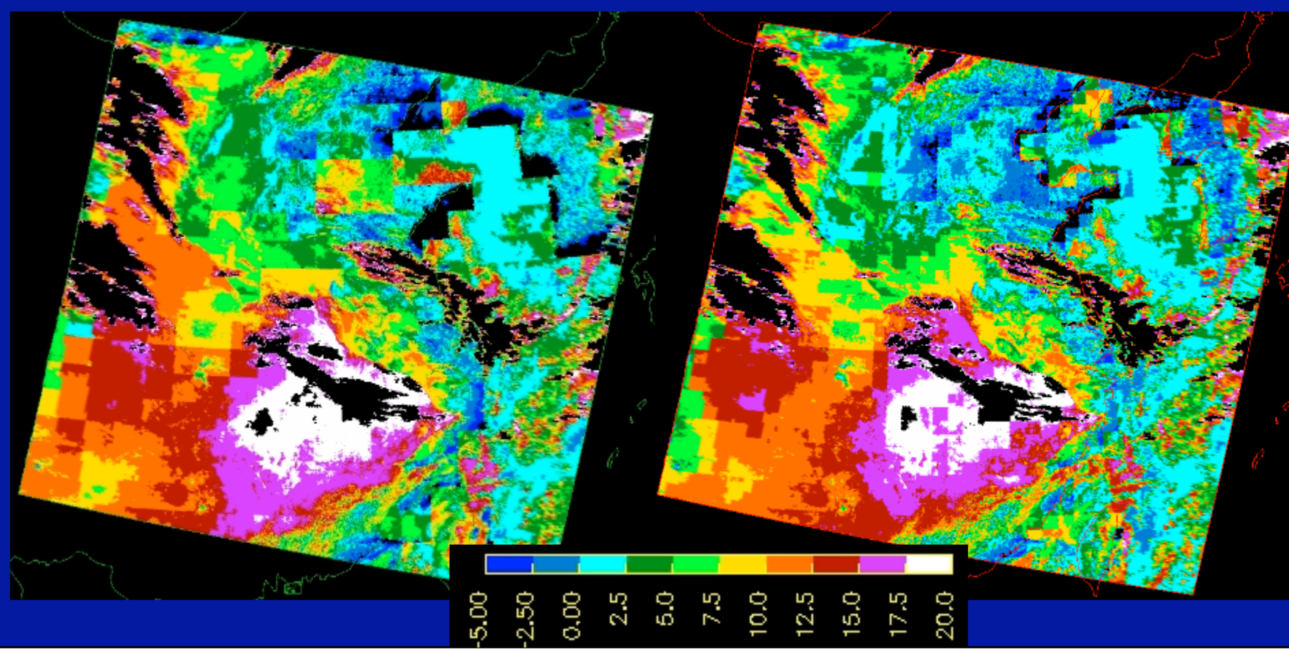


CERES Mask_G5



CST - T11_G4

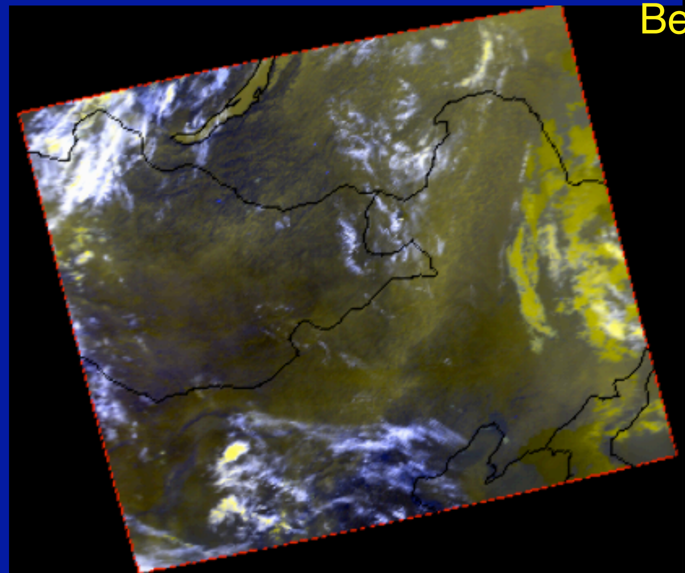
CST - T11_G5



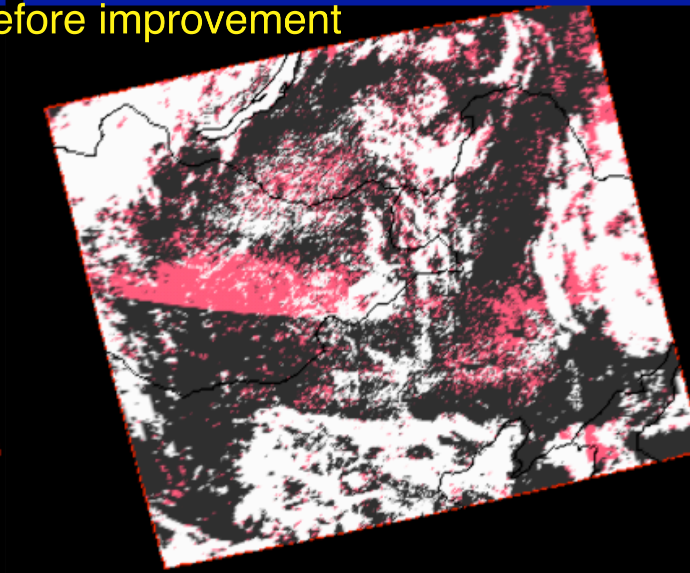
Bo Hai Bay
G4 vs G5
G5 a little better?

CERES Cloud Category

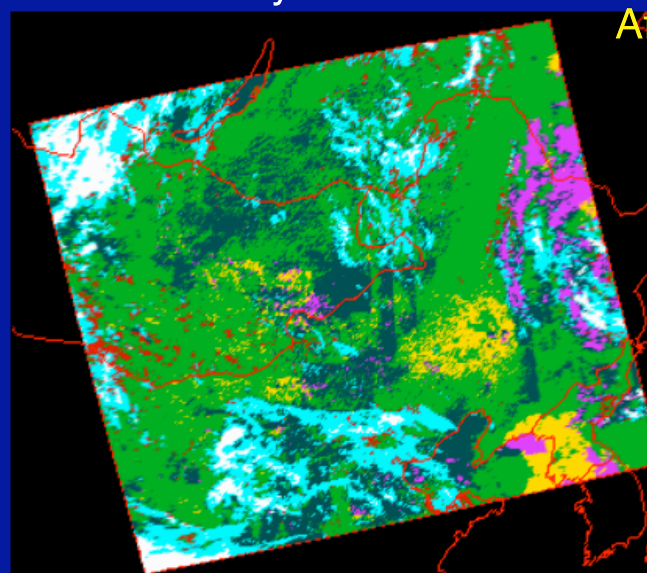
Terra, Nighttime
Mongolia,
20070605, 1415



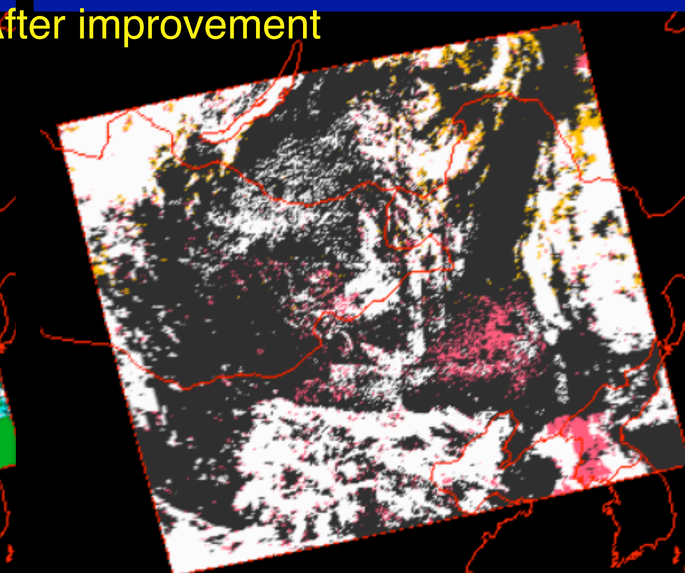
Before improvement



AD Summary



After improvement



Cloud Height Changes

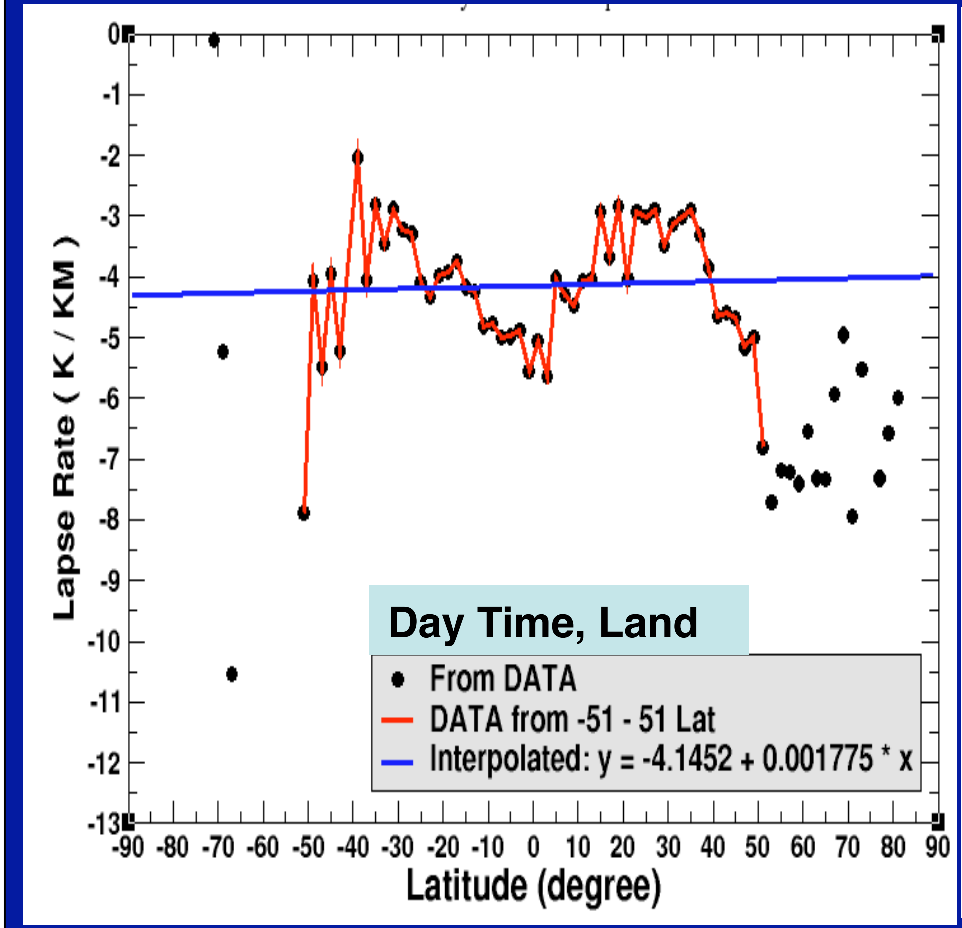
- Regionally and seasonally dependent lapse rate for low clouds
  - year of Aqua & CALIPSO data analyzed
  - see Sun-Mack talk for more detail

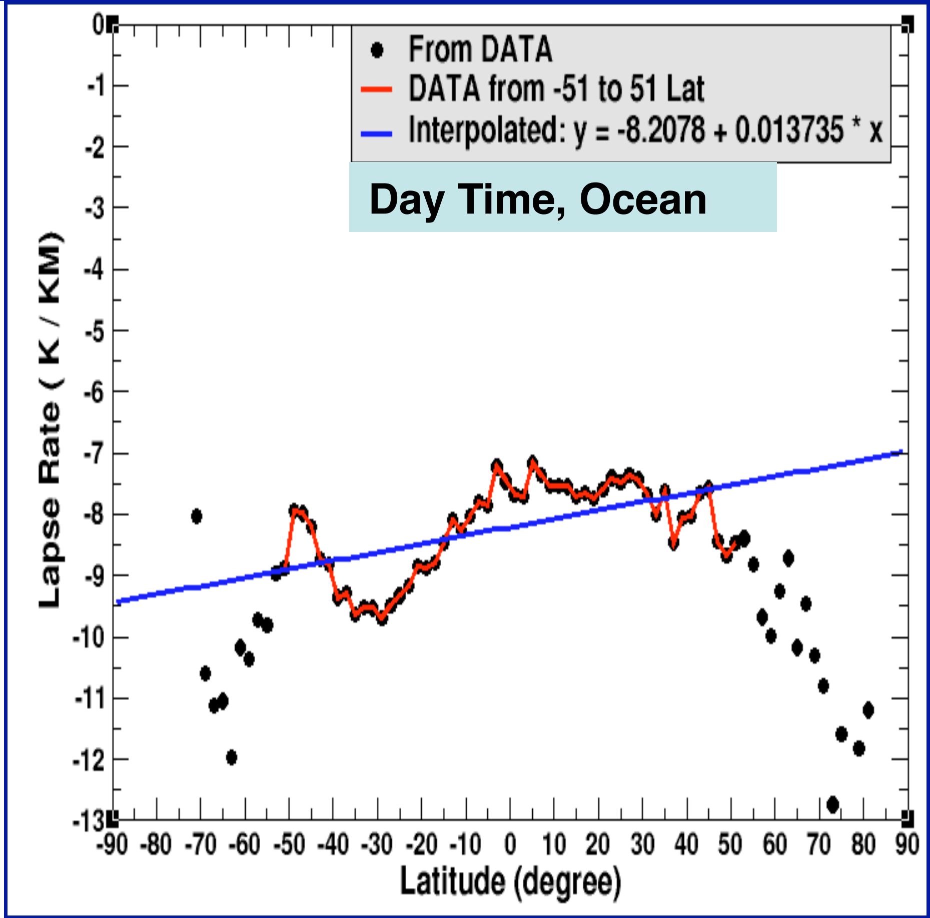
- Overshooting convective cloud heights adjusted
  - overshooting tops identified
  - lapse rate used to take top higher
  - tropopause height no longer cap on CERES cloud tops

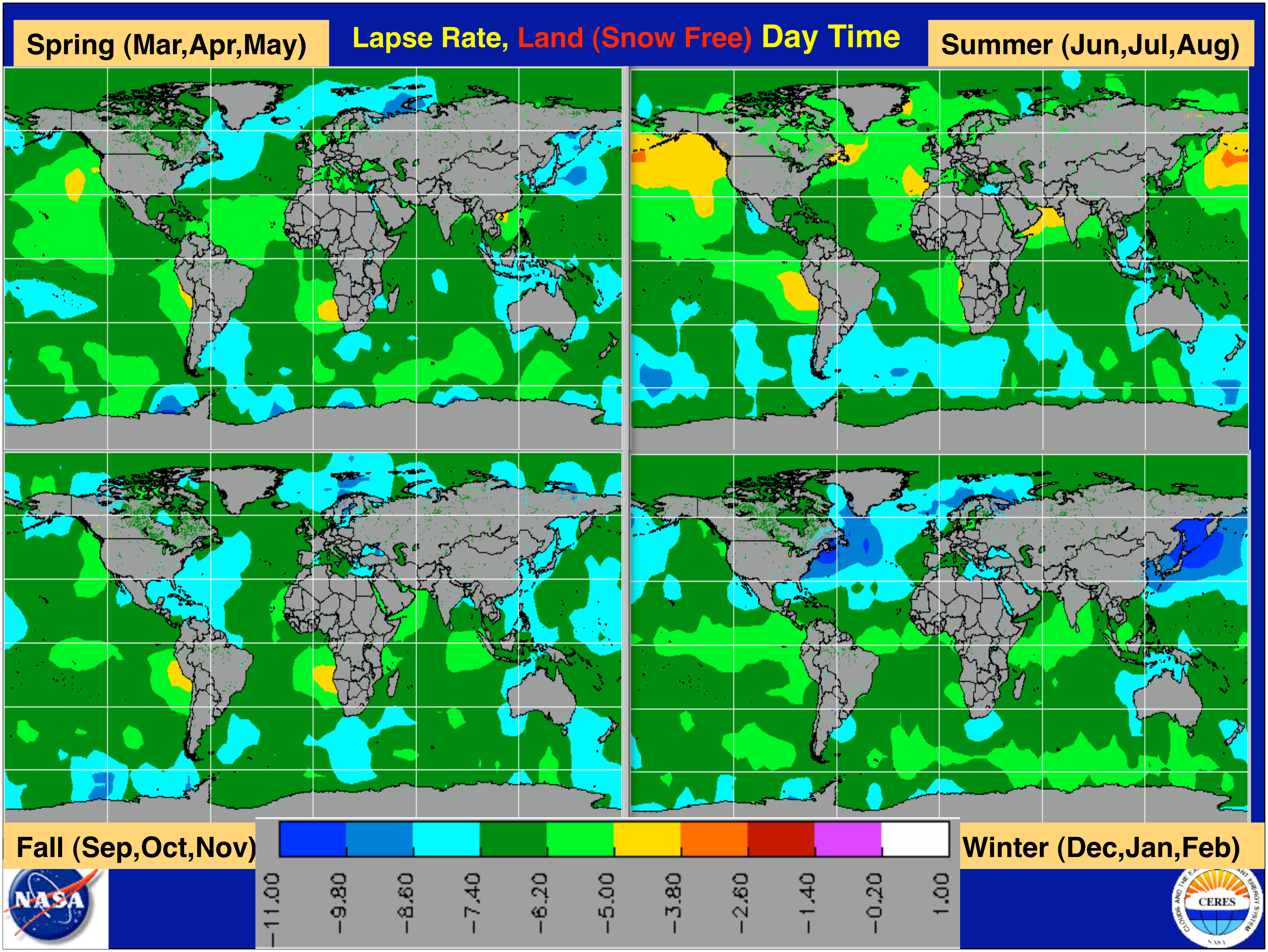
- Changes in CO2 retrievals
  - see later discussion & Chang talk

Zonal Lapse Rate (Derived from Merged April 2007 data)

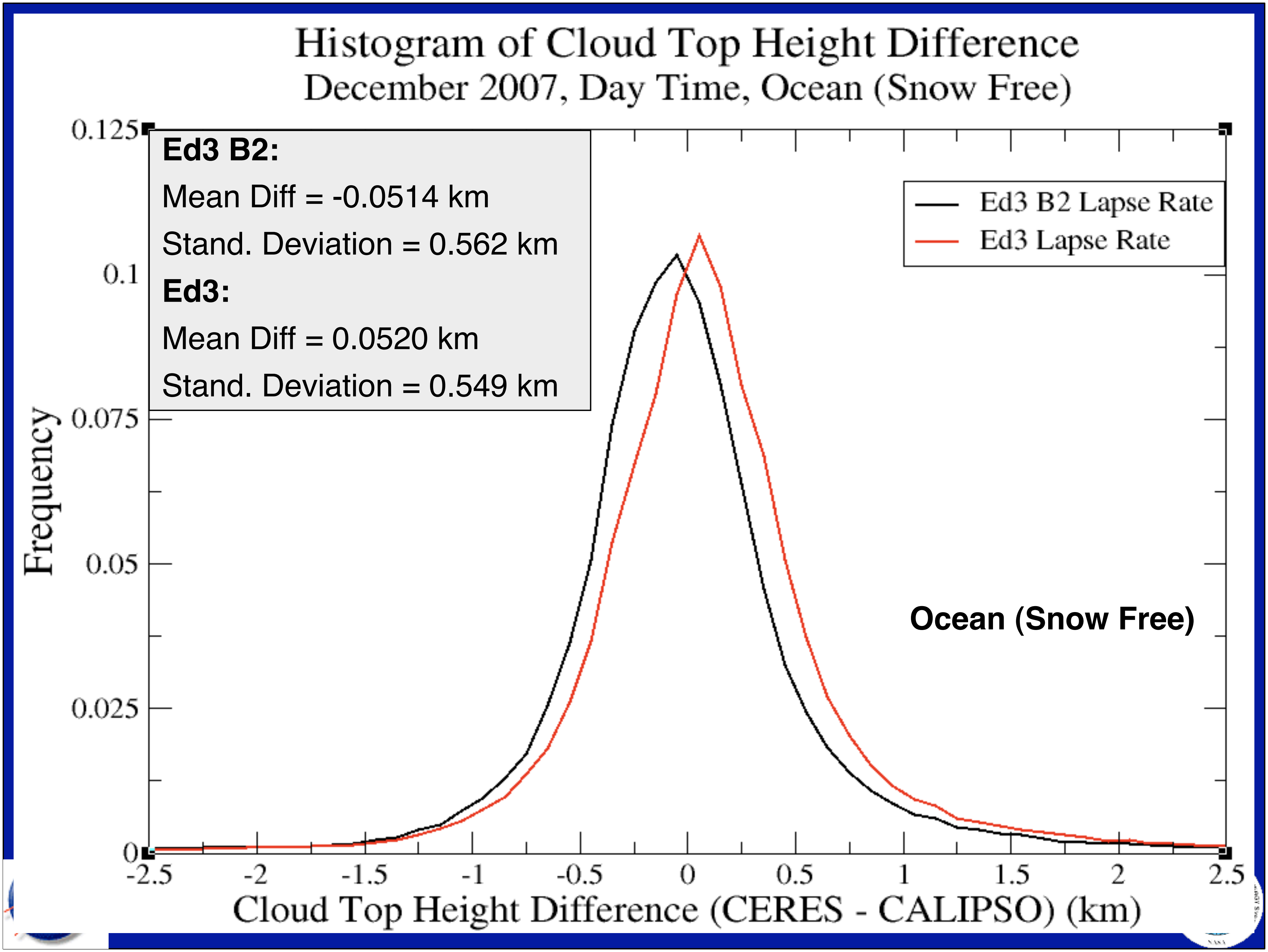
Used in Ed3 Beta2







Spring (Mar,Apr,May)
Lapse Rate, Land (Snow Free) Day Time
Summer (Jun,Jul,Aug)
Fall (Sep,Oct,Nov)
Winter (Dec,Jan,Feb)
-11.00
-9.80
-8.60
-7.40
-6.20
-5.00
-3.80
-2.60
-1.40
-0.20
1.00
NASA
CERES



Histogram of Cloud Top Height Difference
December 2007, Day Time, Ocean (Snow Free)
Ed3 B2:
Mean Diff = -0.0514 km
Stand. Deviation = 0.562 km
Ed3:
Mean Diff = 0.0520 km
Stand. Deviation = 0.549 km
Ed3 B2 Lapse Rate
Ed3 Lapse Rate
Ocean (Snow Free)
Frequency
0.125
0.1
0.075
0.05
0.025
0
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
Cloud Top Height Difference (CERES - CALIPSO) (km)

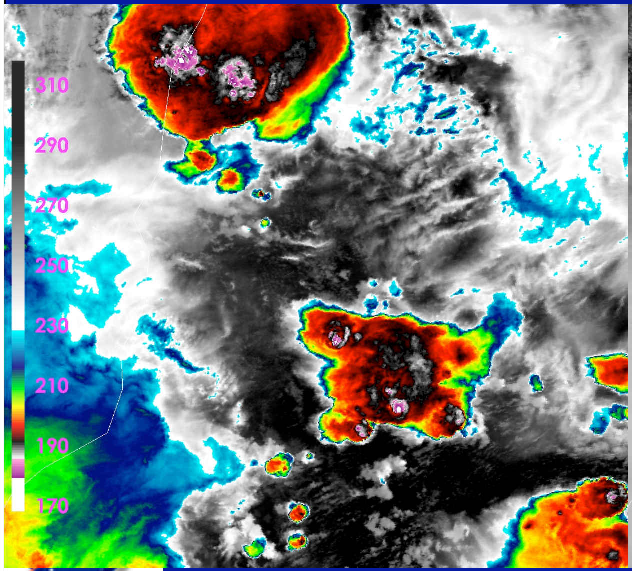
Using Objective Overshooting Top Detections To Improve CERES Convective Cloud Top Height

Issue: Cloud tops in convective updrafts often reach heights far above the tropopause (i.e. overshooting tops), but Ed2 assigned them to MOA-defined tropopause height. Observed cloud top temperatures are significantly colder than any point in the MOA profile, so no realistic height can be assigned.

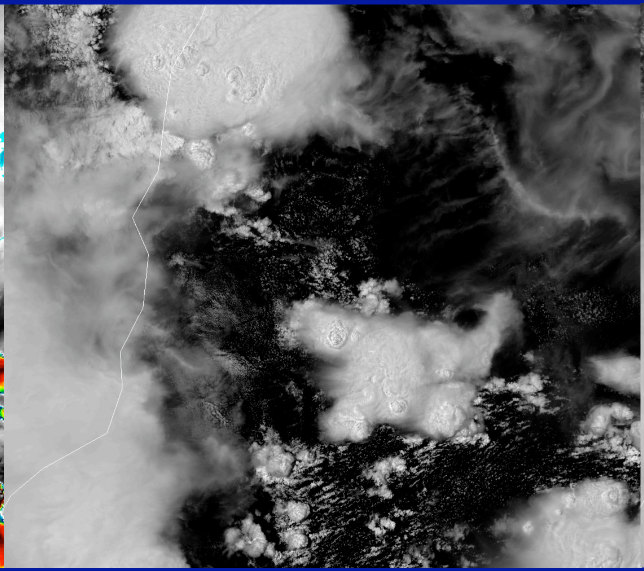
Solution: Use objective overshooting cloud top detection algorithm to improve cloud top height assignment in these regions. Combine -8 K/km lapse rate with difference between cloud top & MOA tropopause temperature to adjust cloud top height in overshooting top regions

Aqua MODIS Example: Congo, 3/19/2009, 1225 UTC

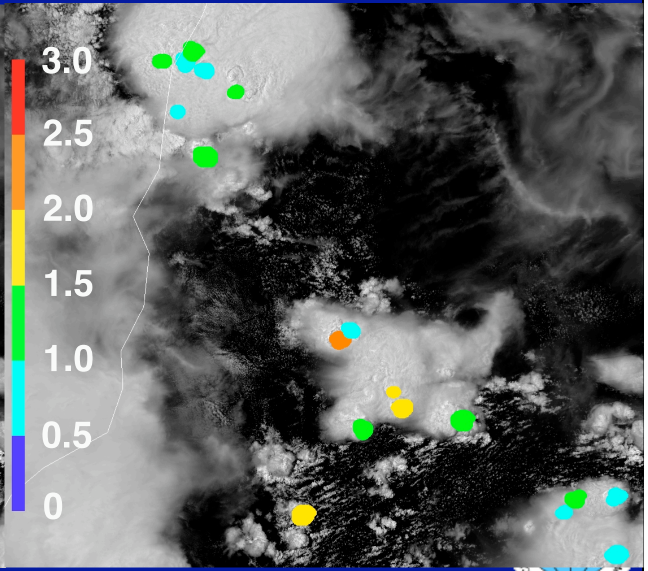
1 km 11-μm BT



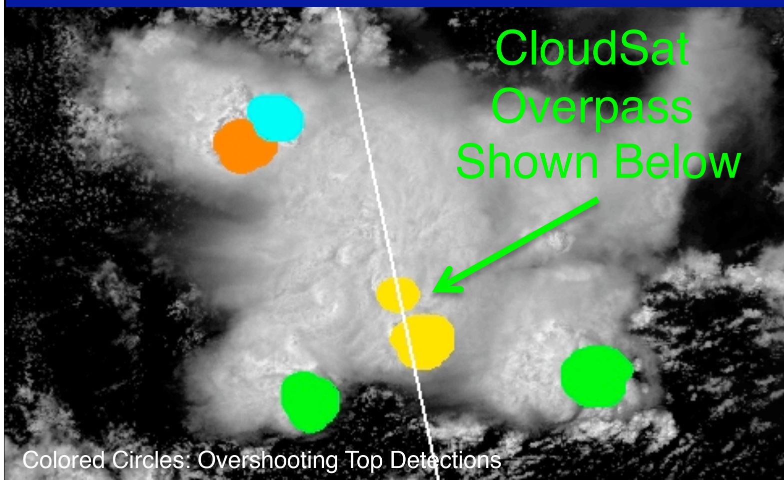
0.25 km Visible



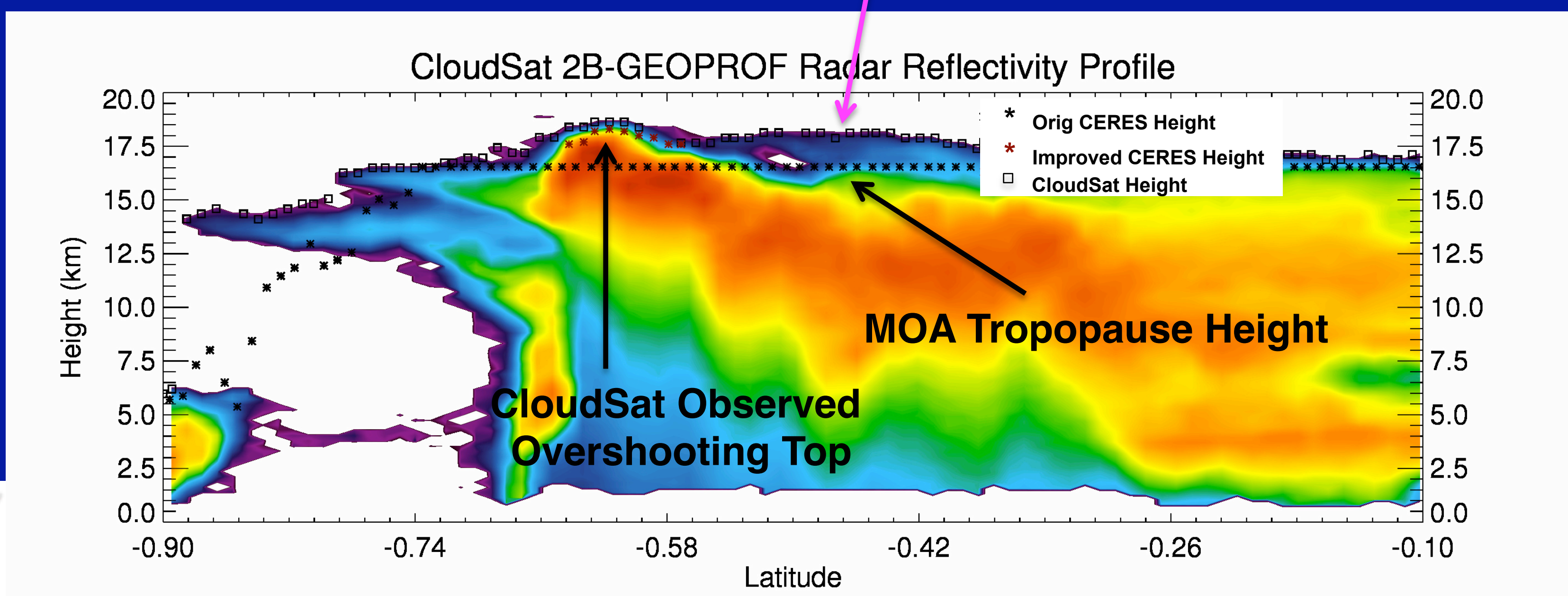
0.25 km Visible w/ overshooting top detections colored by height adjustment



Using Objective Overshooting Top Detections To Improve CERES Convective Cloud Top Height



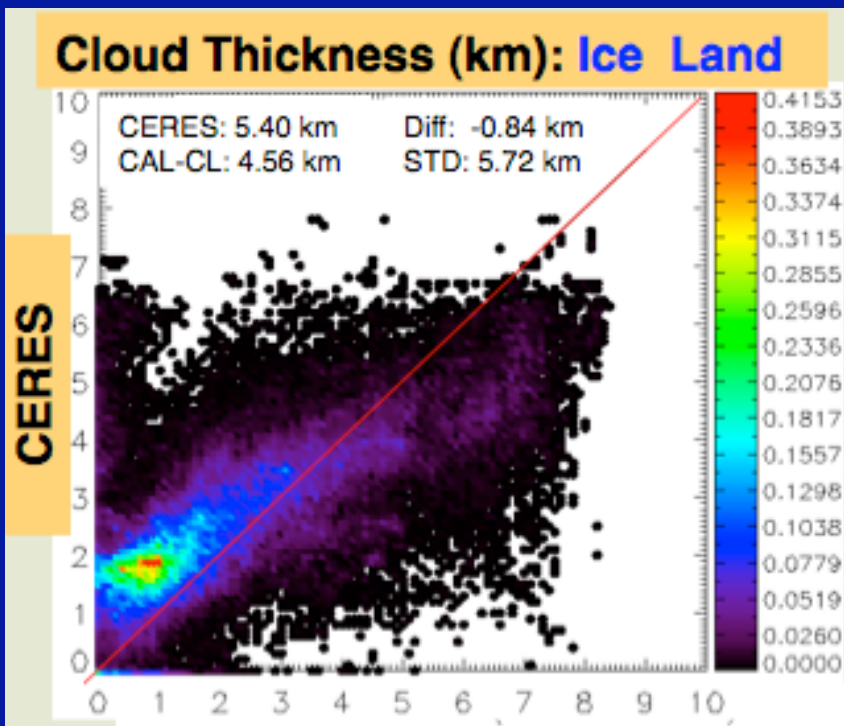
- Height adjustment in overshooting top (OT) regions integrated into CERES Ed3 cloud algorithms
  - OT algorithm utilizes gradients in 11-μm channel temperatures for detection (Bedka et al., *JAMC*, 2010)
  - OT algorithm validated using 1.5 yrs of CloudSat OT observations: POD=75% FAR: 16%
- Example below shows new height adjustment to Z_c better matches CloudSat heights
  - Additional 0.5-km increase will be applied to estimate Z_t

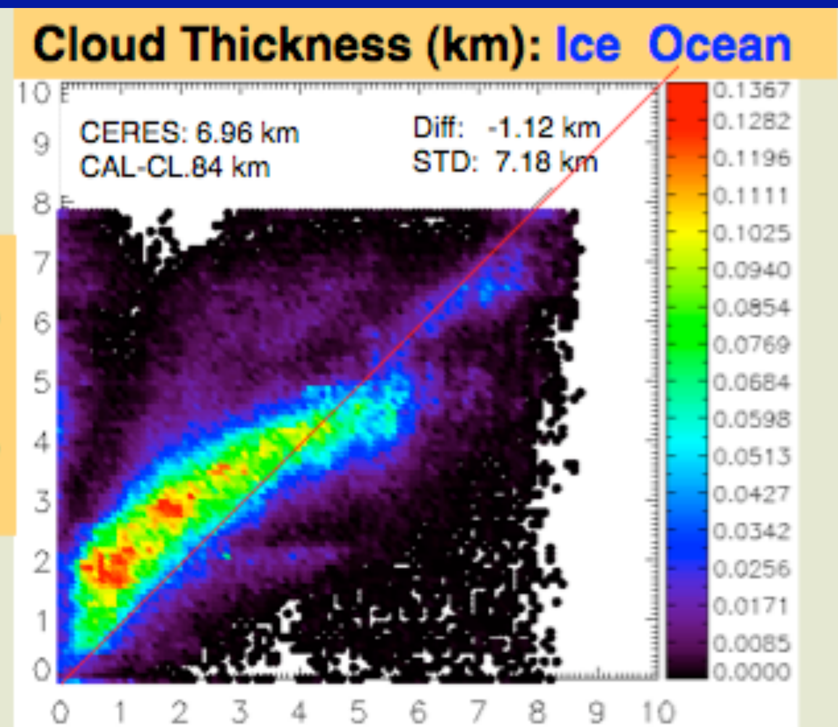


Improvements in Cloud Thickness Parameterizations

- Bugs in Ed3 Beta2 code fixed
  - *SZA improperly determined for thickness calculations*

Results from Ed3 beta2b





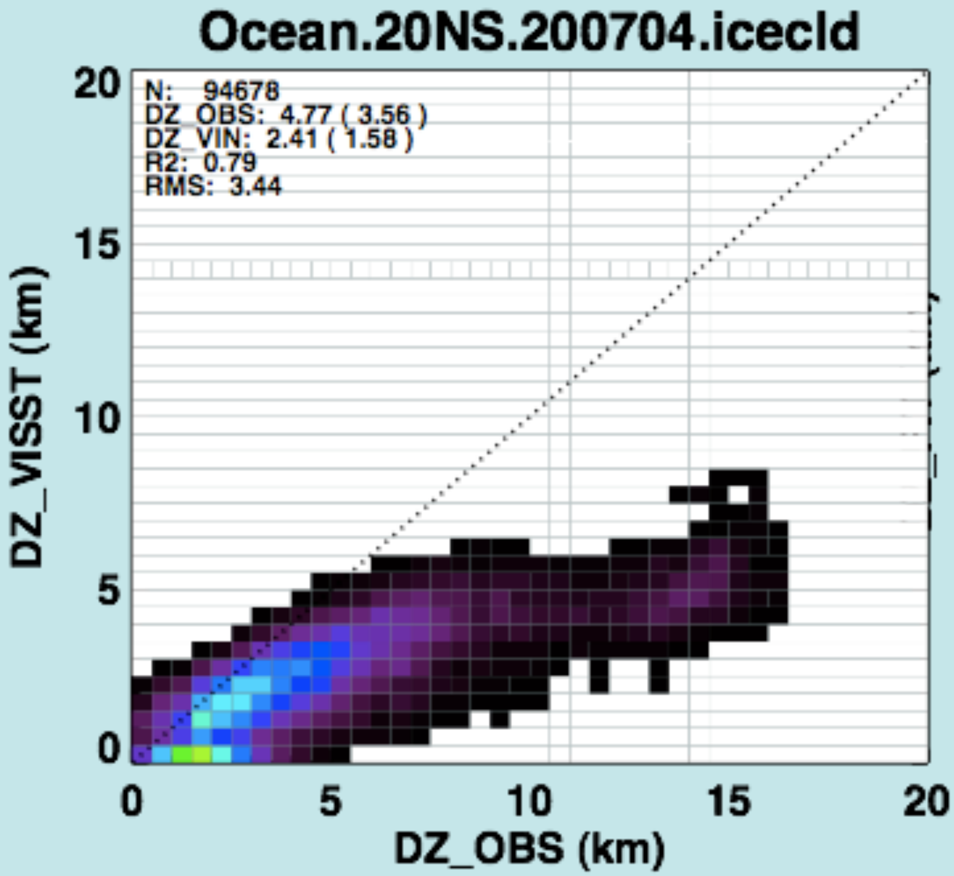
200702
Single Layer

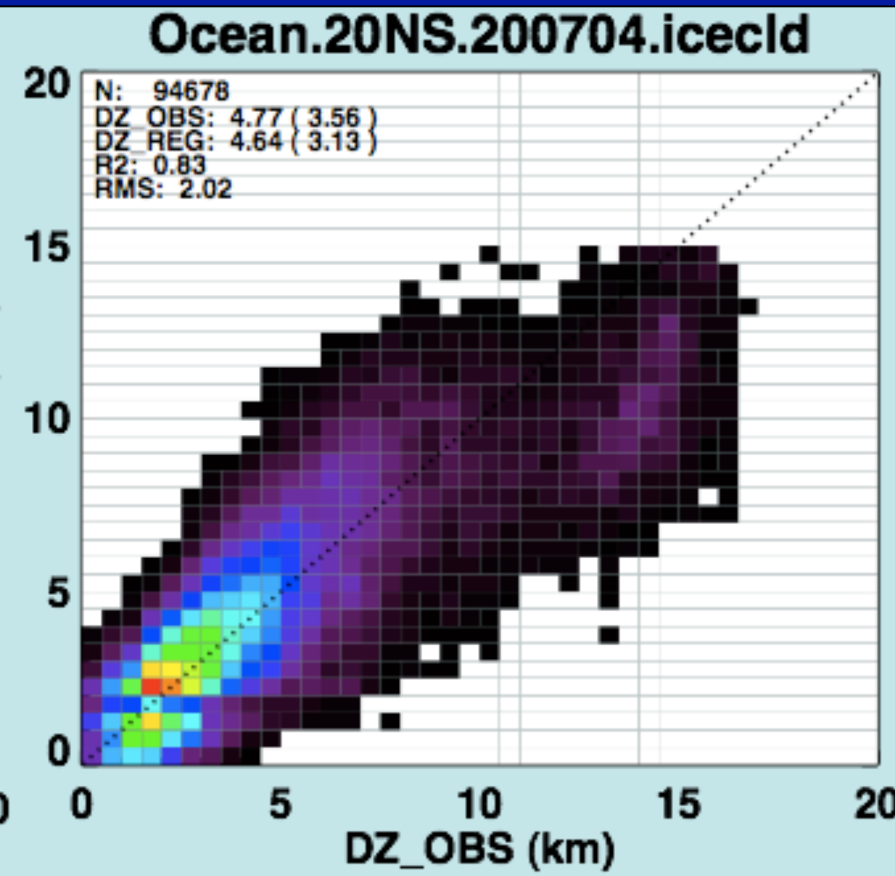
CAL-CL: CALIPSO cloud top and CloudSat Cloud Base with no precipitation

Bias: -0.84km

Bias: -1.12km

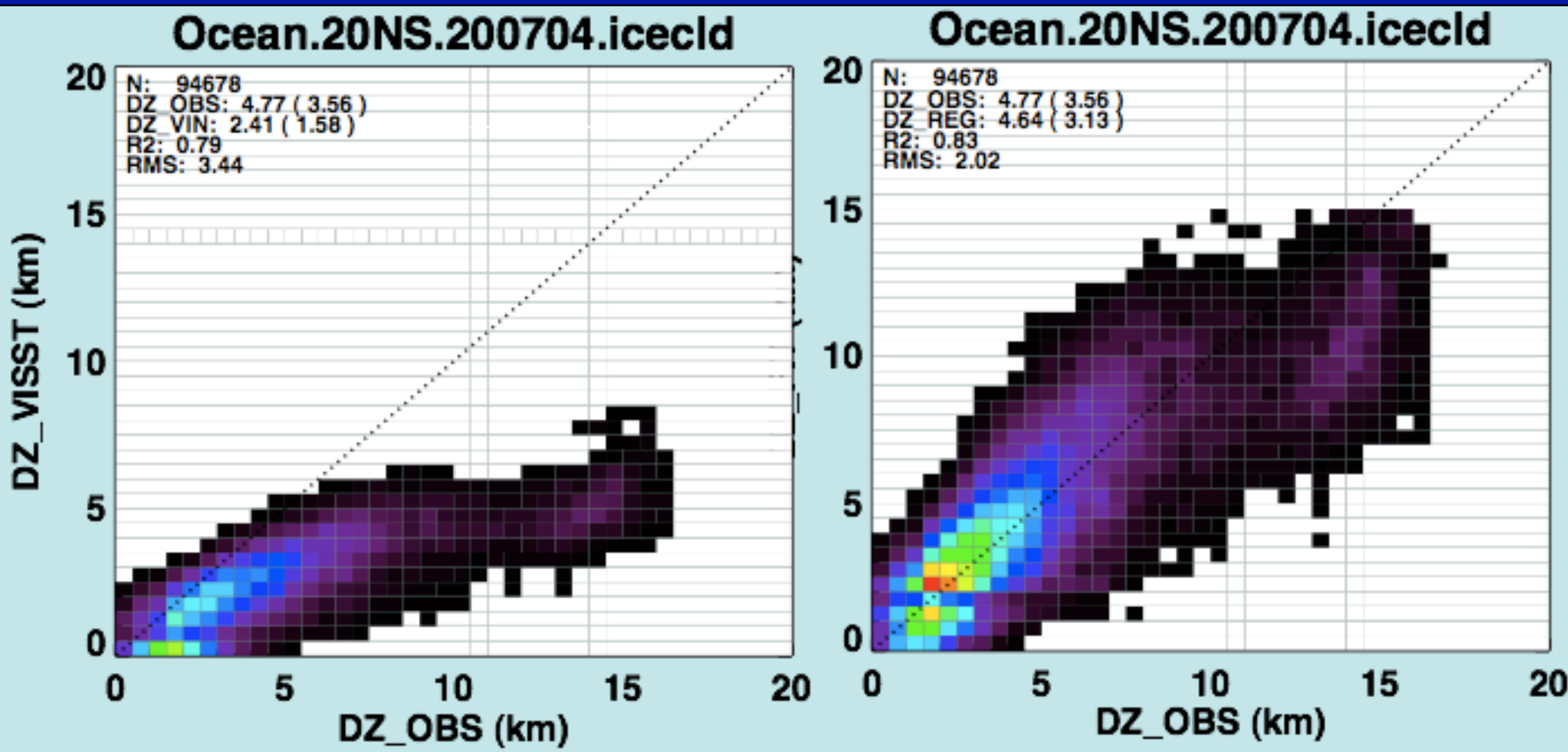
Ice Clouds over Ocean
Tropical (20N-20S)





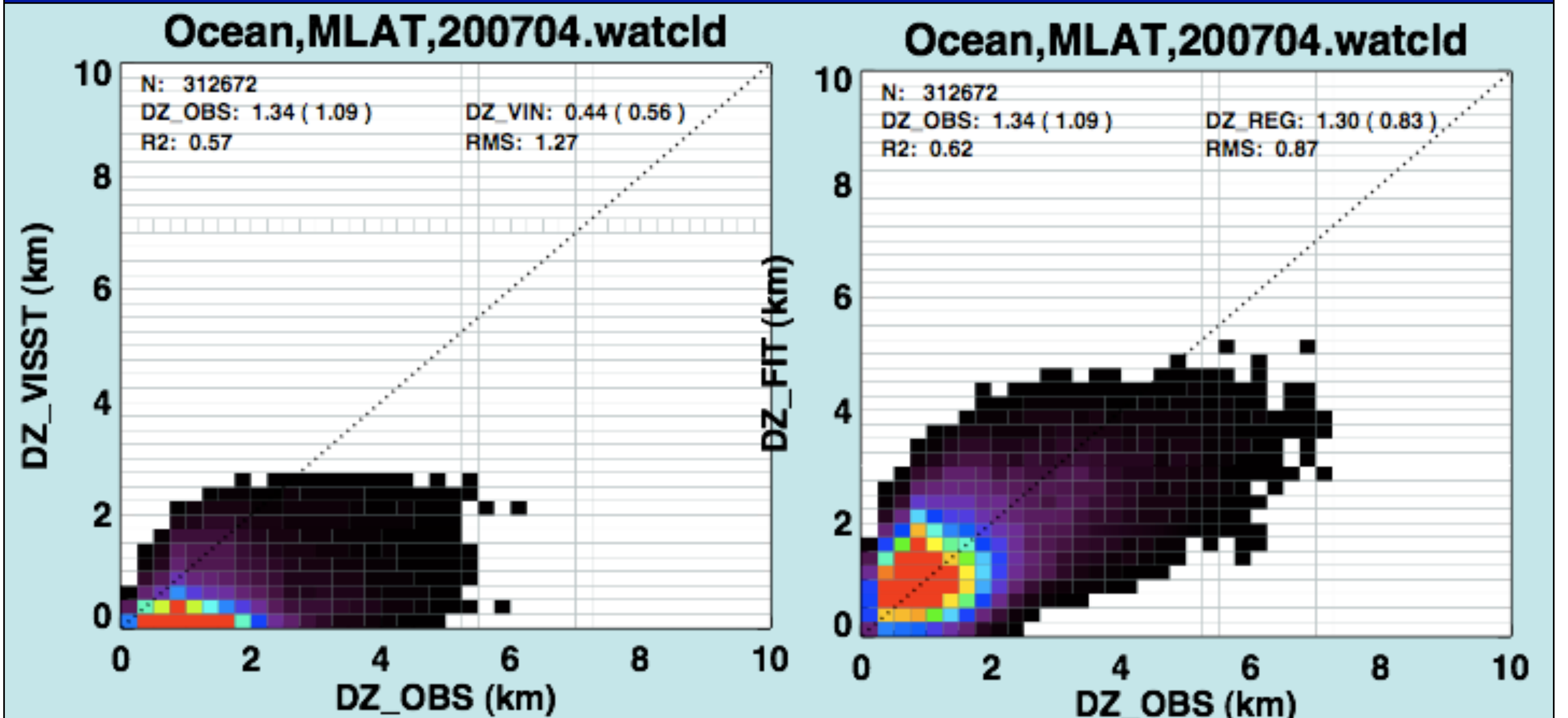
Bias reduced from 2.36km to 0.13km
rms reduced 1.42km

Ice Clouds over Ocean
Tropical (20N-20S)



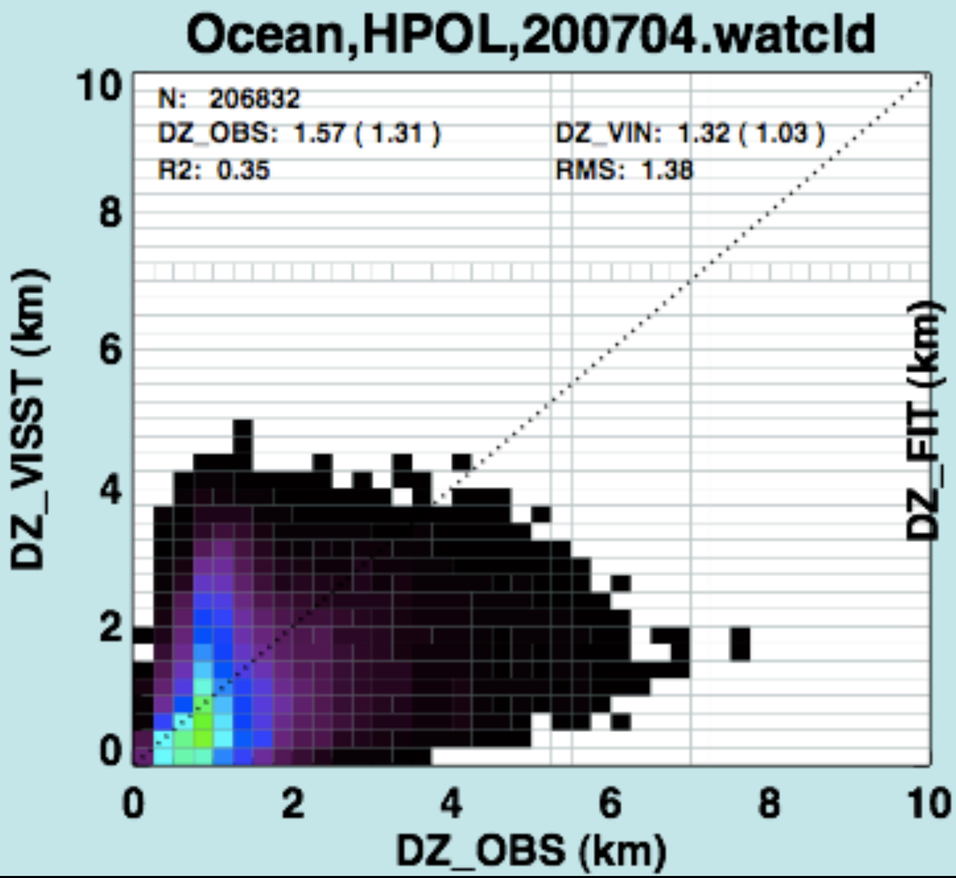
Bias reduced from 2.36km to 0.13km
rms reduced 1.42km

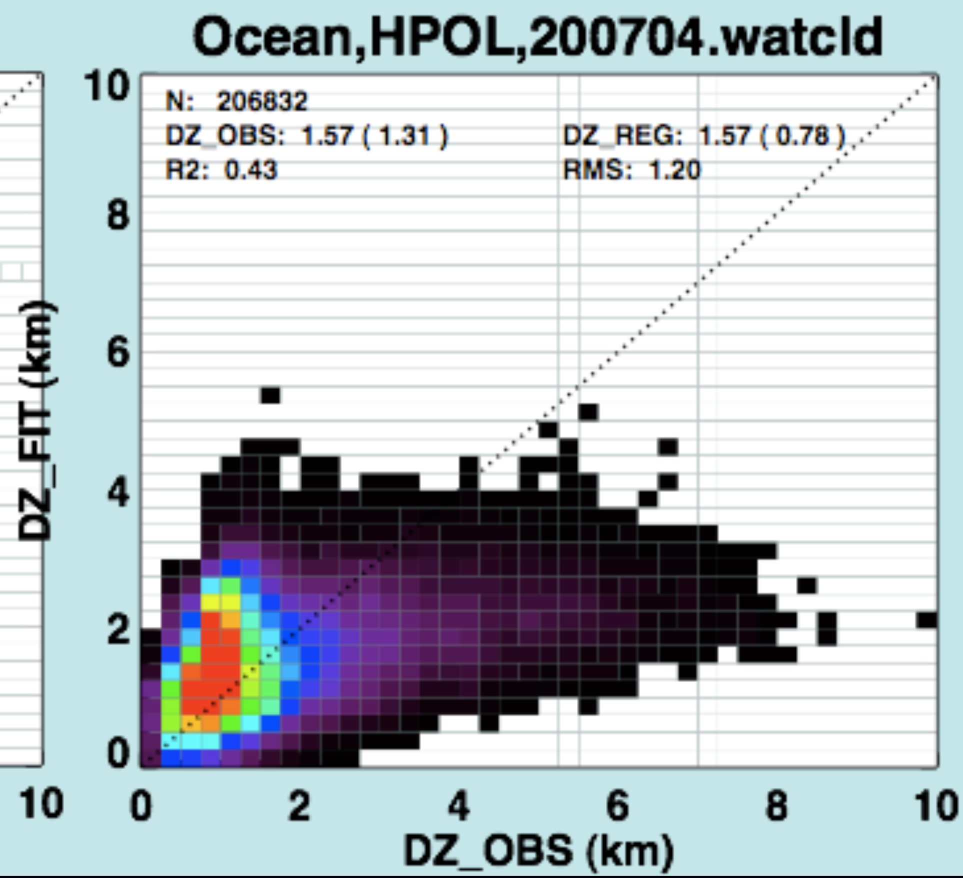
Water Clouds over Ocean
Mid Lat (50-20 N/S)



Bias reduced from 0.9 to 0.04km
rms reduced 0.4km

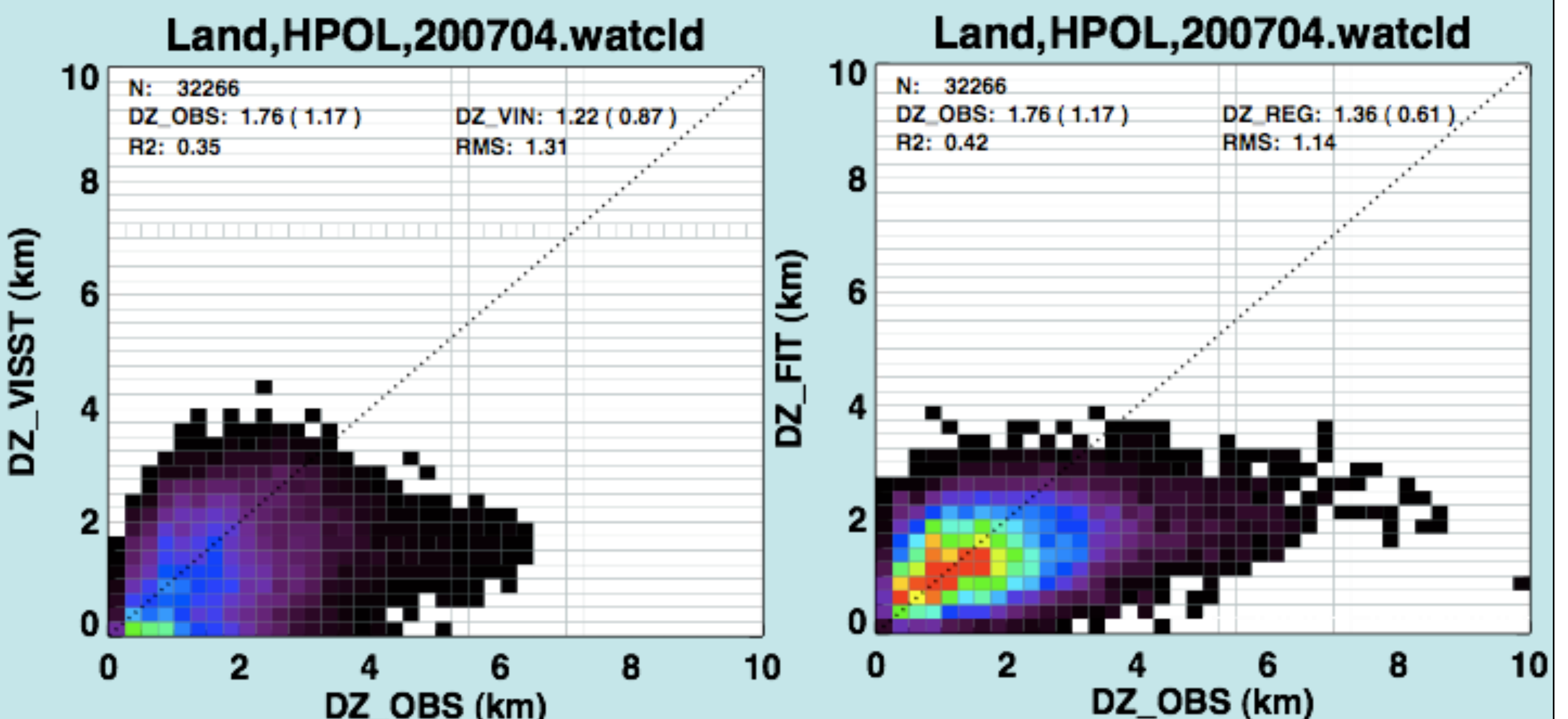
Water Clouds over Ocean
High Lat (50-90 N/S)





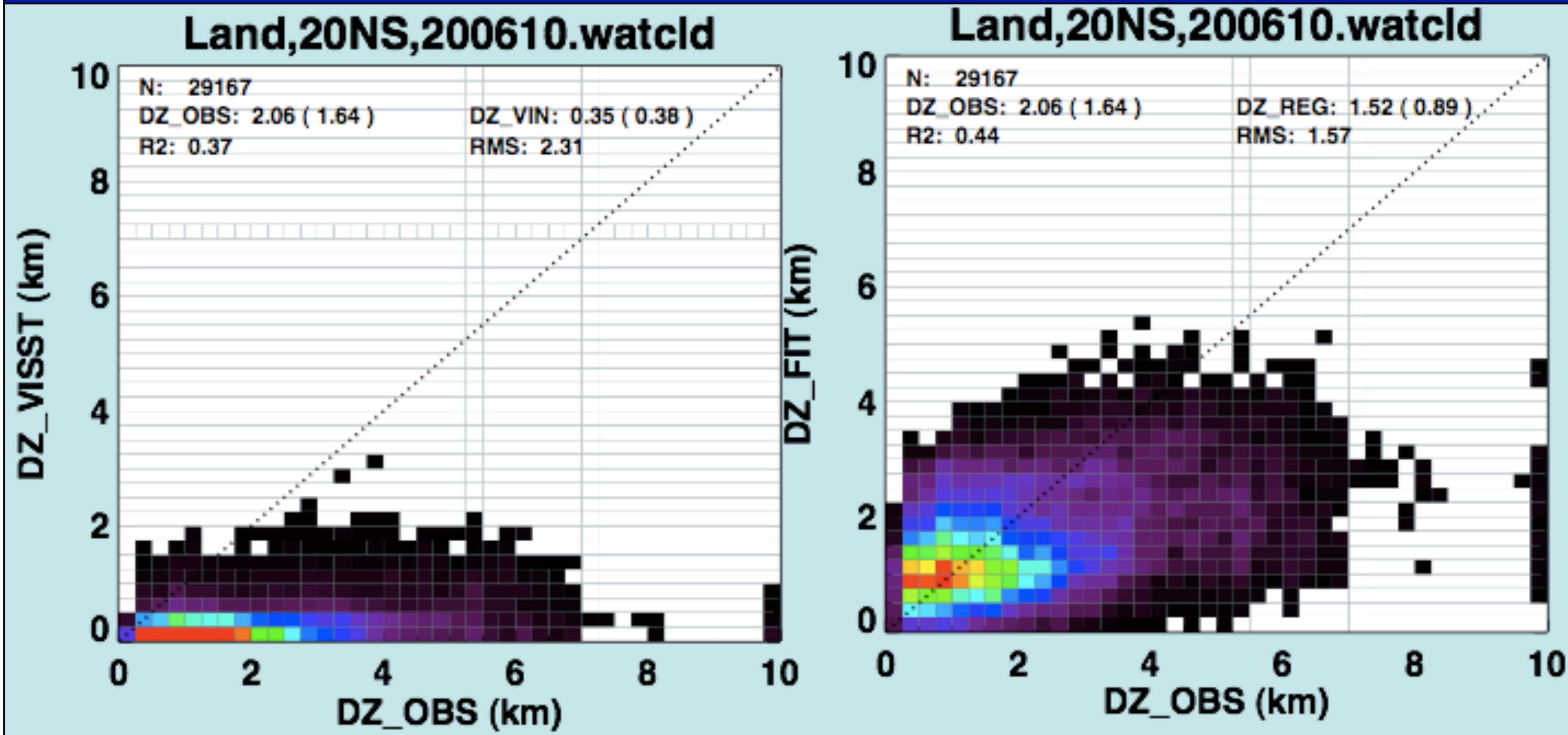
Bias reduced from 0.25 to 0 km
rms reduced by 0.18 km

Water Clouds over Land
High Lat (50-90 N/S)



Bias reduced from 0.5 to 0.4 km
rms reduced by 0.2 km

Water Clouds over Land
Tropical (20N-20S)



Bias reduced from 1.7 to 0.5 km
rms reduced by 0.7 km

Cloud Thickness Summary

• Edition 3 beta-2 bugs discovered & eliminated

• New parameterizations dramatically decrease thickness biases found in Ed2 results

• Parameterization based on single-layer clouds

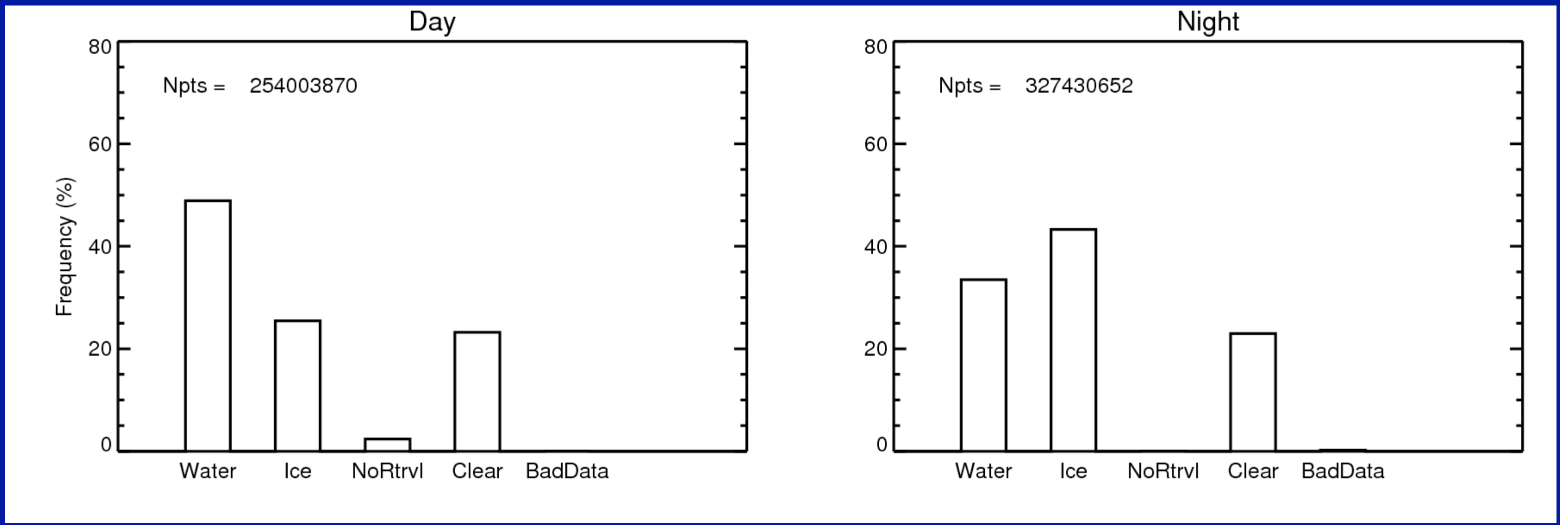
- can be applied *post facto* to multilayered clouds

• Additional improvements possible

- reduce rms by modeling as function of cloud type
- not until Ed4

Nocturnal Phase Classification

- Large diurnal difference in Ed2 ice cloud percentage

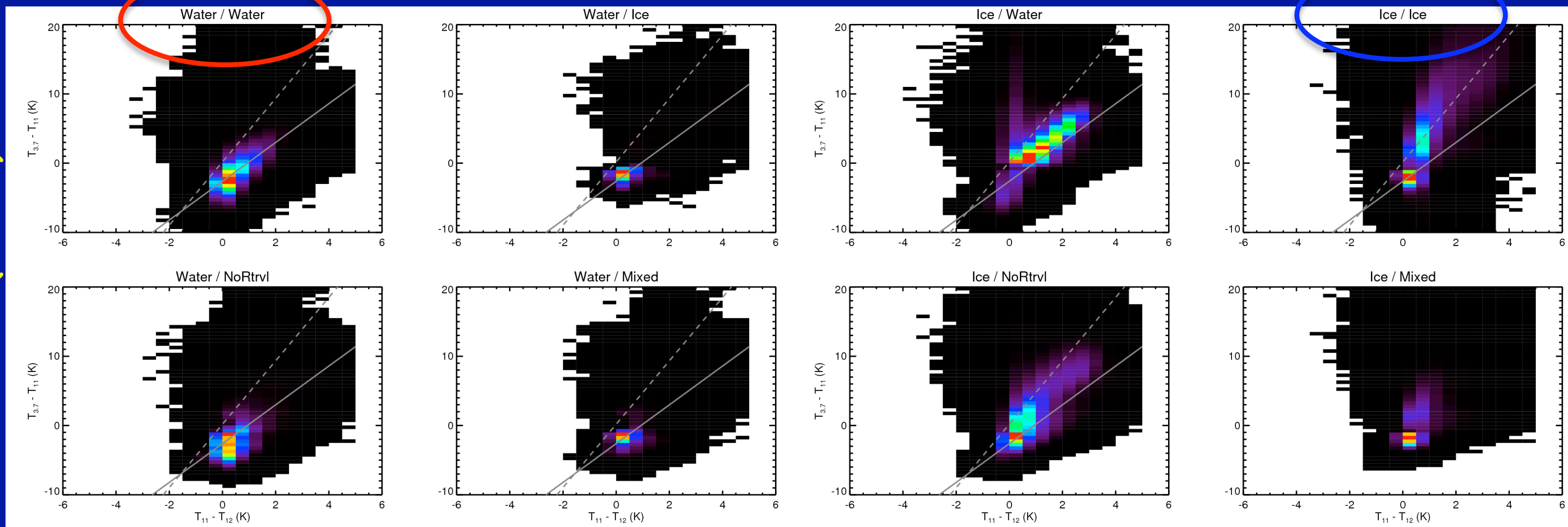


- Bi-spectral method BSM (Baum et al.) minimal help
  - uses 8.6 – 12-μm BTD
  - too many mixed phase & no decision

- Trispectral method to reclassify mixed phase & no decision pixels
  - uses 3.7-11 and 11-12 BTDs
  - tunes linear fits to SIST and Bispectral agreement cases

SIST / BSM Cloud Phase

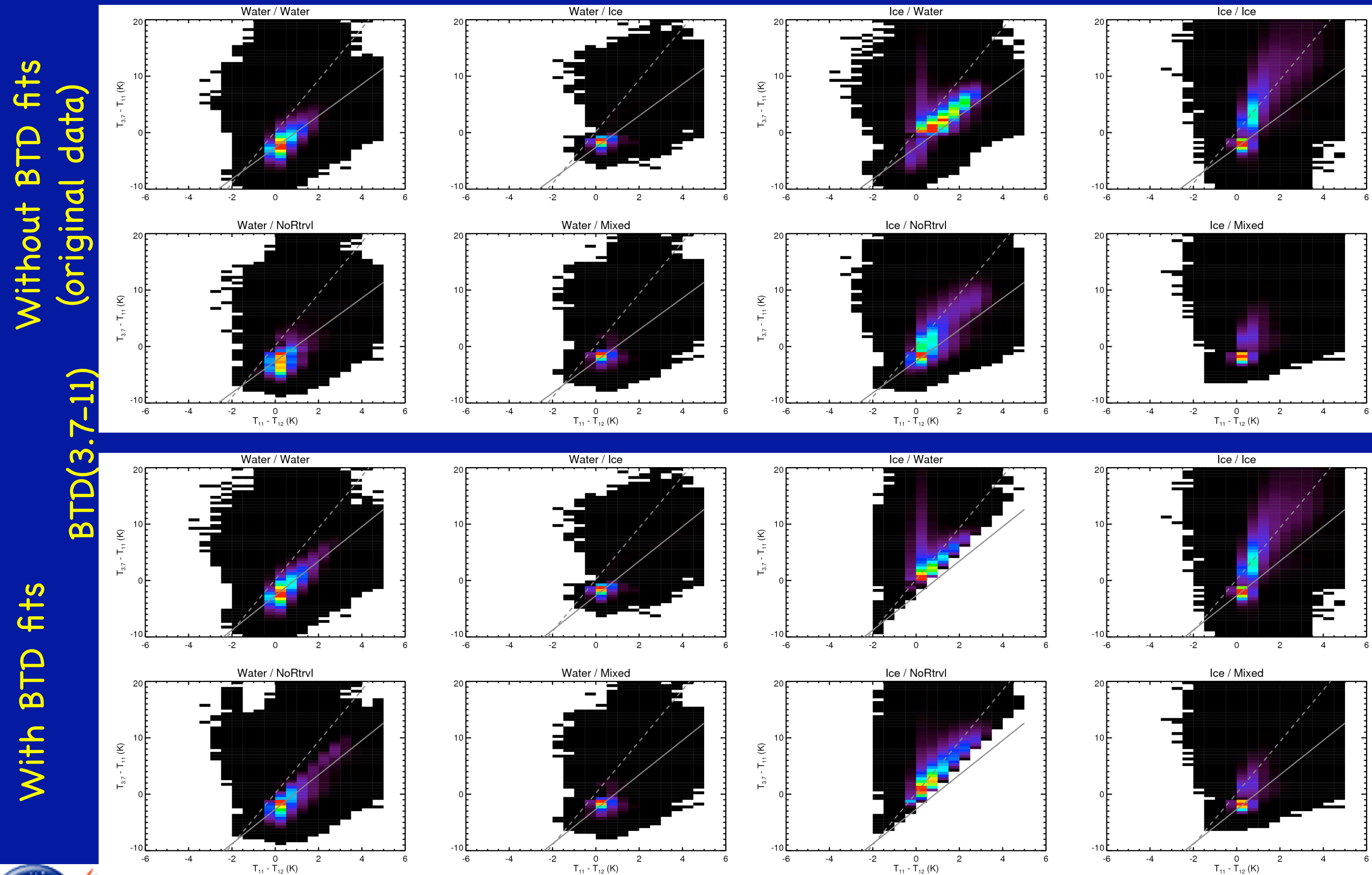
BTD(3.7-11)



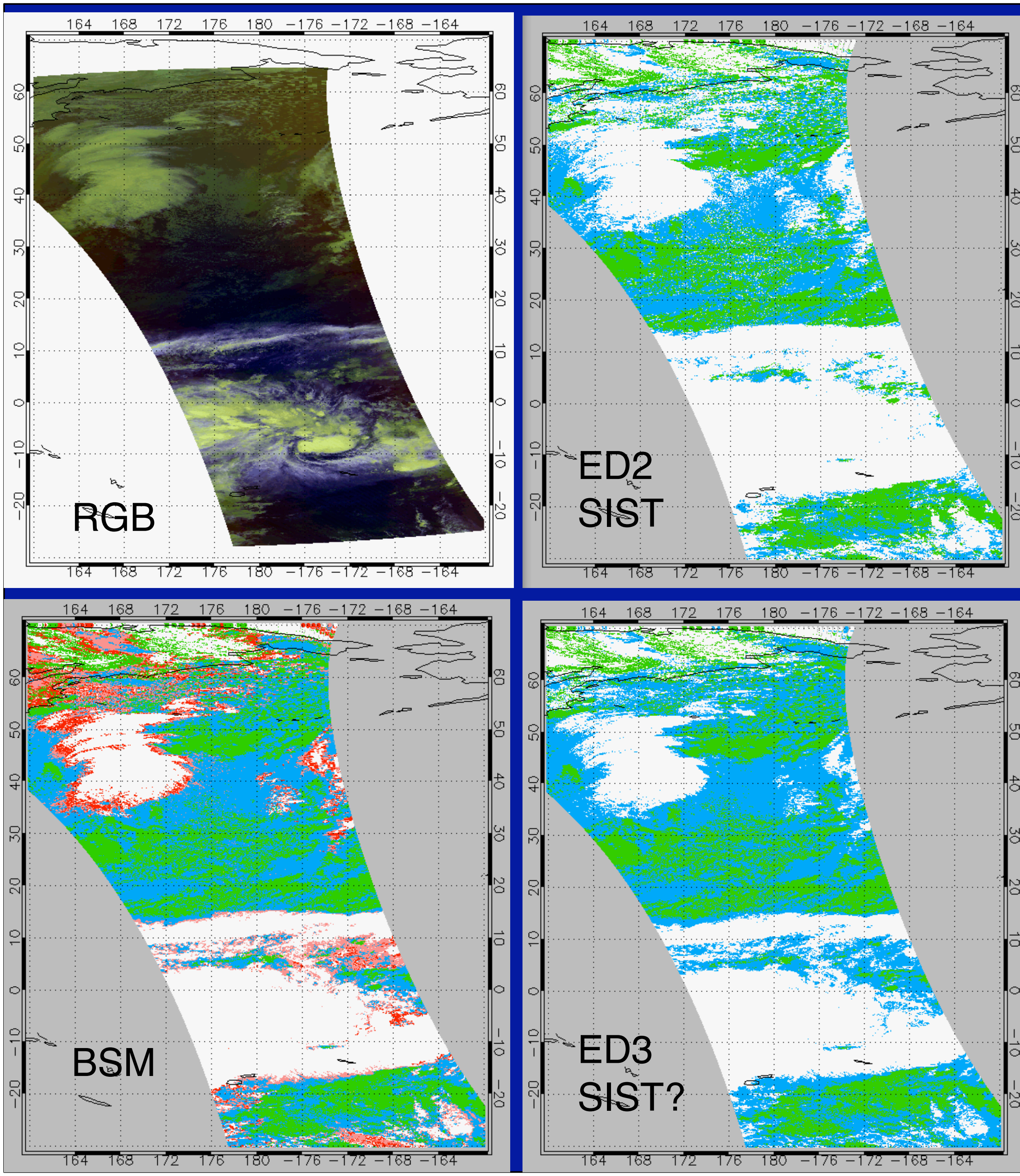
BTD(11-12)

- BTD(11-12) vs BTD(3.7-11)
  - Linear fits based on Water/Water and Ice/Ice plots
  - Solid line -> Water fit, Dashed line -> Ice fit
  - Slope of Ice fit is steeper than for the Water fit (i.e., BTD(3.7-11) is greater for Ice clouds)

Results



BTD(11-12)

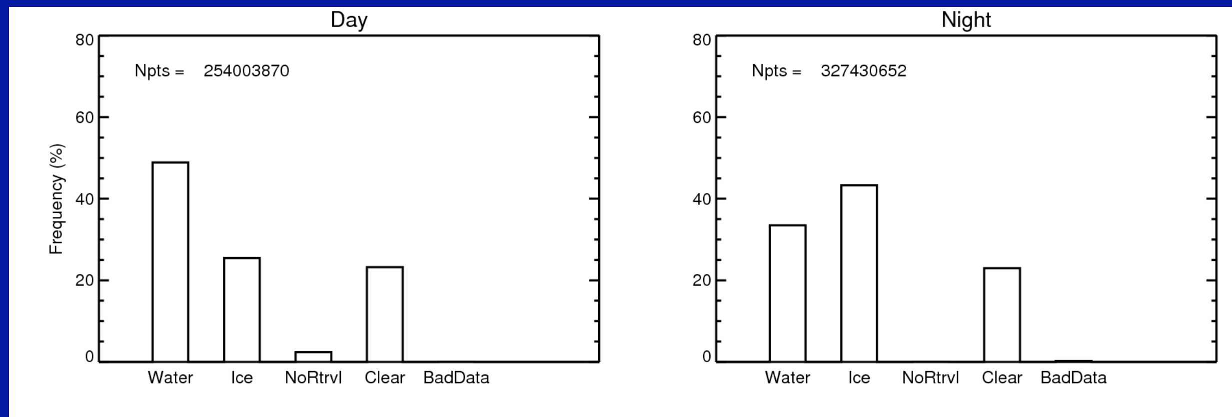


Example Case over Ocean, Jan 11, 2004

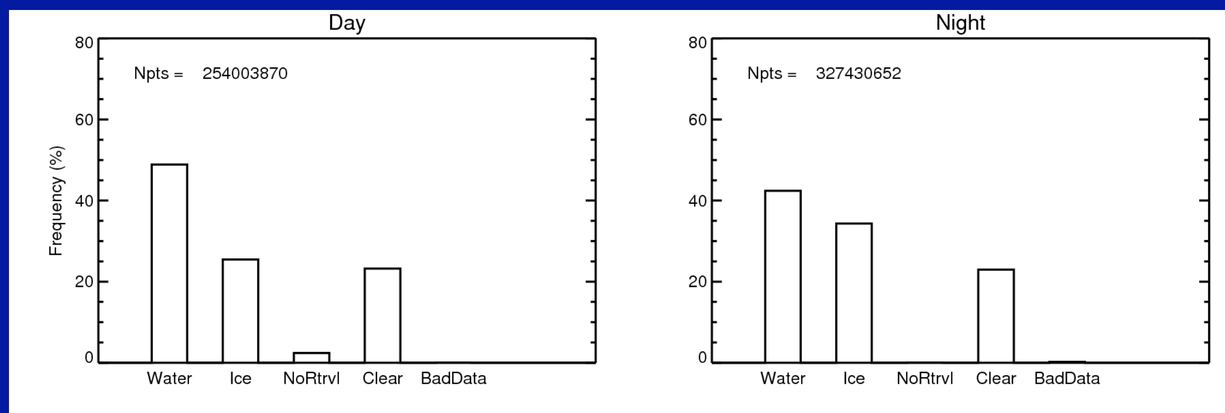
- Ed2 classifies some obvious low clouds as ice
- BSM classifies some as water, others as mixed/no decision (red/ pink)
- Ed3 SIST decides on all pixels based on BSM and TSM. Most obvious low clouds now water

SIST / BSM Cloud Phase

Without BTD fits
(original data)



With BTD fits



- Applied fits to Ice/Water and Ice/NoRtrvl cases for nighttime pixels over ocean
- More (supercooled) water cloud, less ice cloud, over ocean using fits to guide phase selection process; more realistic distributions

Nocturnal Phase Classification Summary

- Diurnal difference in ice cloud percentage reduced
  - remainder may be due to overlapped clouds

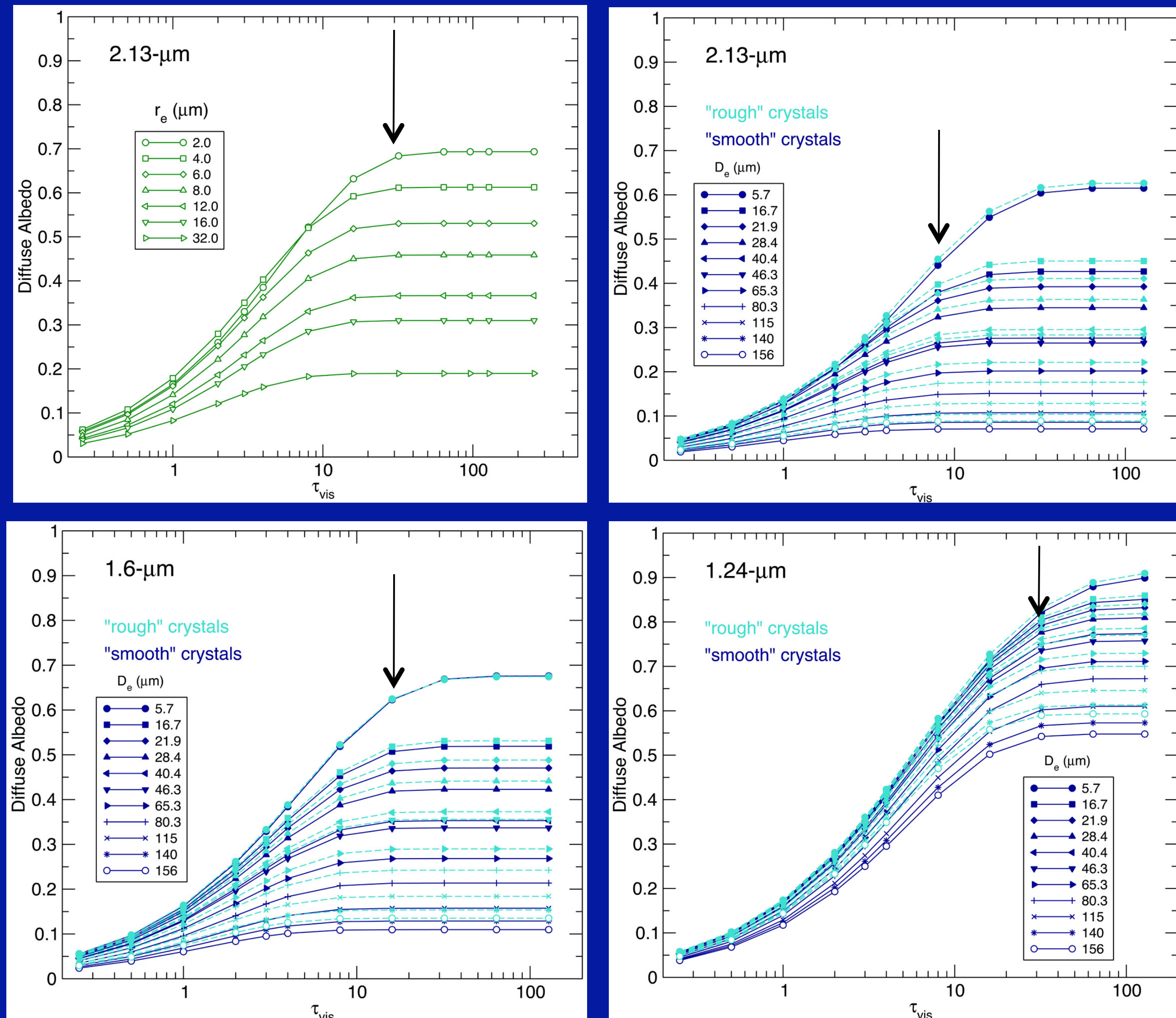
- More testing needed
  - examine use of 8.6 – 12-*μ*m BTD
  - test over different surfaces and months
  - look at $T_c(CO_2)$ to aid classification

- Trispectral method to reclassify mixed phase & no decision pixels
  - uses 3.7-11 and 11-12 BTDs
  - tunes linear fits to SIST and Bispectral agreement cases

Retrieval of Properties over Snow

- 2.13-μm channel only good for small optical depth clouds
- 1.24-μm channel appears to be good candidate
- Requires good estimates of background albedos
  - need both snow-covered & snow-free albedo maps
  - monthly dependent

Diffuse Cloud Albedos from Adding-Doubling Computations



2.13-μm

- water limit: $\tau = 16$
- ice: $\tau < 8$

1.6 μm

- ice limit: $\tau = 16$

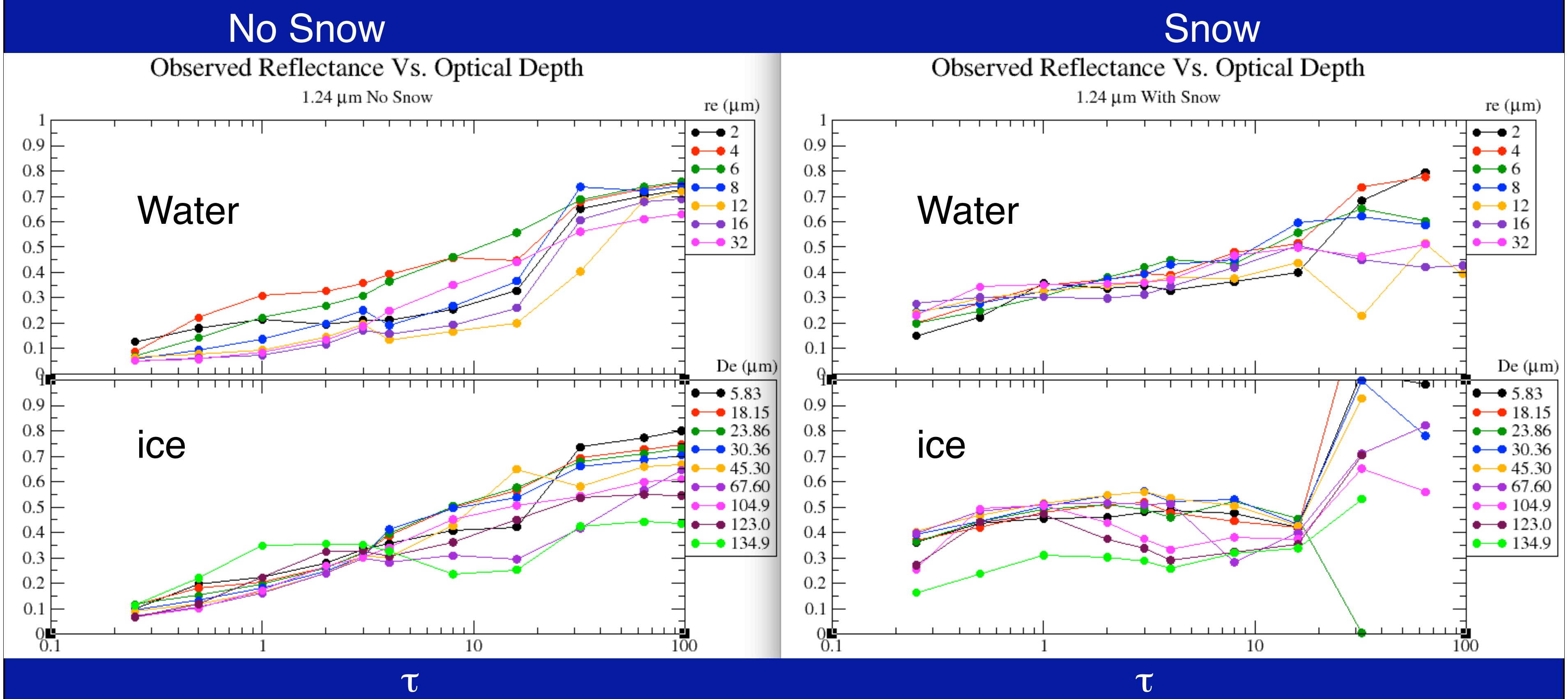
1.24 μm

- ice limit: $\tau > 32$

1.24 μm channel has more promise for getting most of full range of τ

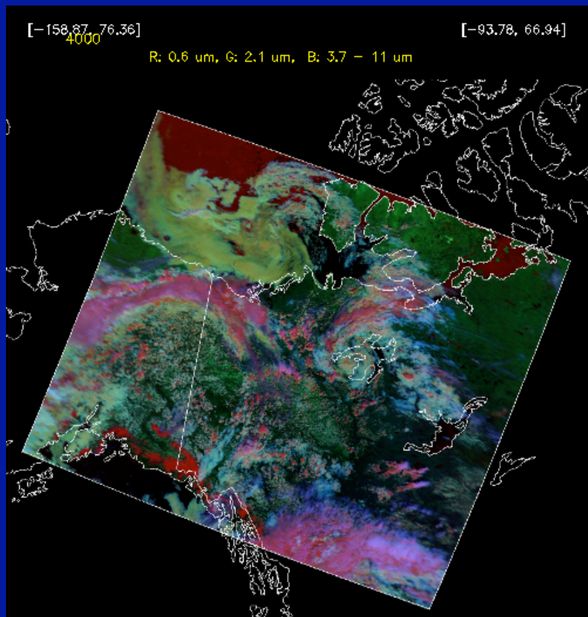
- MODIS team using 1.24 μm over snow

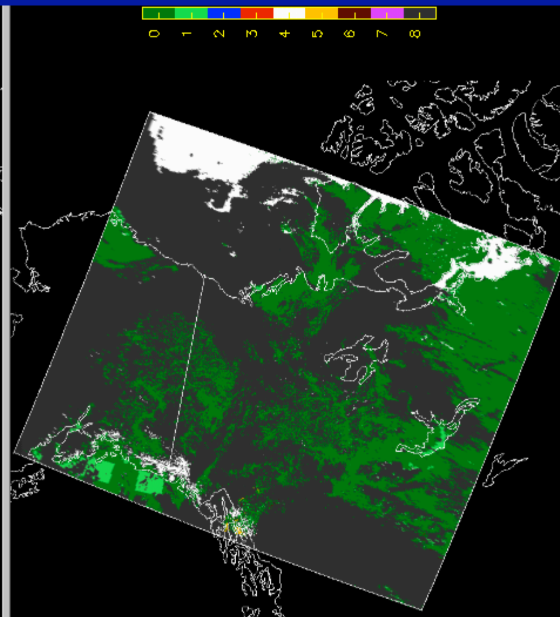
1.24-μm Cloud Reflectances Observed from Aqua MODIS
Jan-Feb 2007

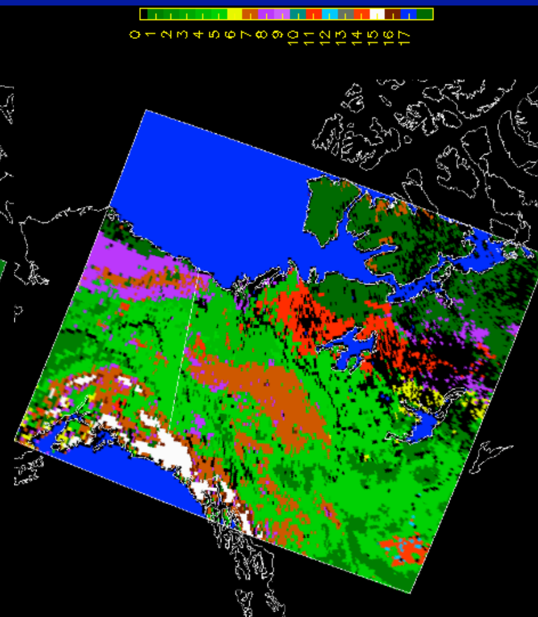


- Reflectance optical depth ranges similar to theoretical model results
  - *problems with high end over snow due to 2.1 retrieval*
- Particle size dependence not entirely monotonic
  - *possible sampling biases*

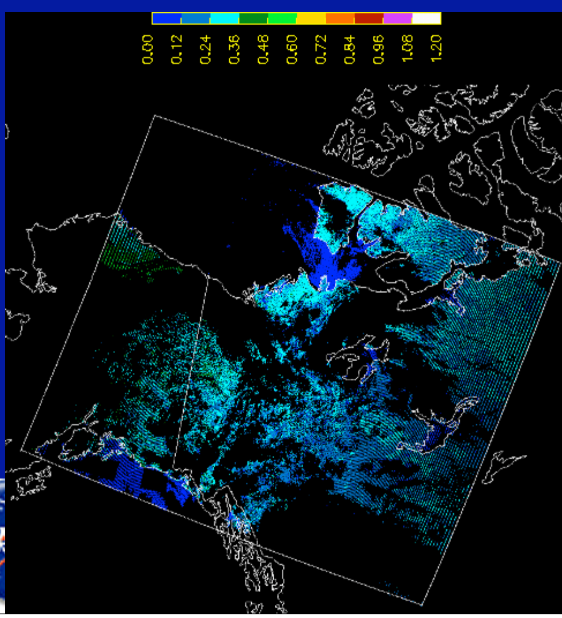
July 2007 Terra MODIS
1.24 µm Reflectance comparison



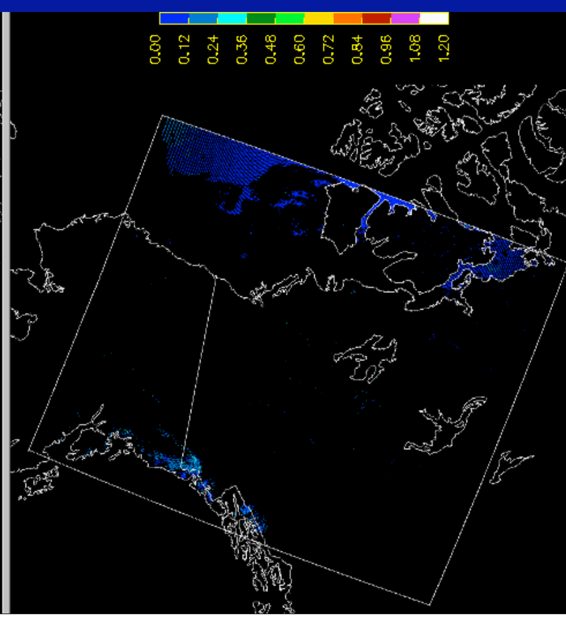




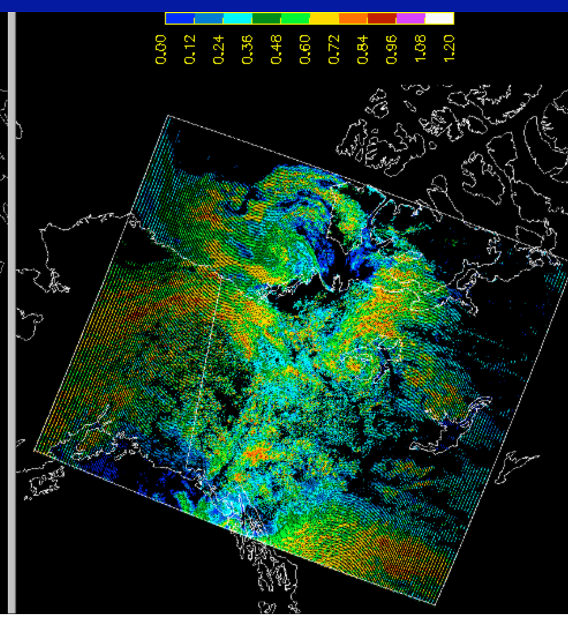
Strong Clear Pixels w/o Snow



Clear Pixels with Snow



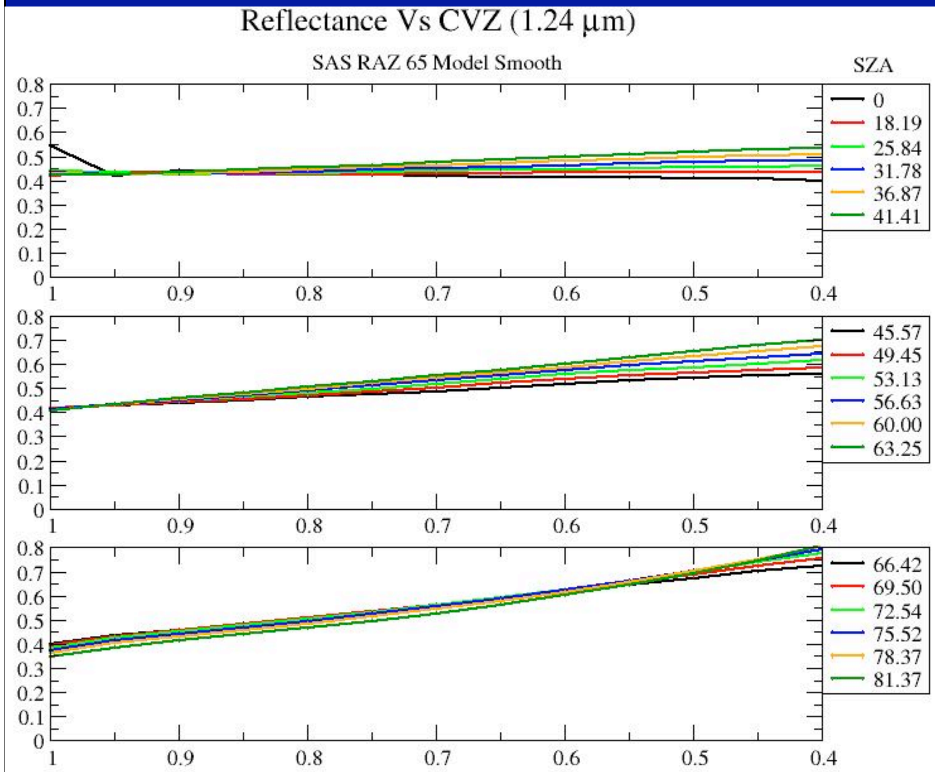
Cloudy Pixels



Comparison of 1.24-μm Clear Snow Reflectances from Model Calculations & Observed from Aqua MODIS, RAZ = 65°, Jan-Feb 2007

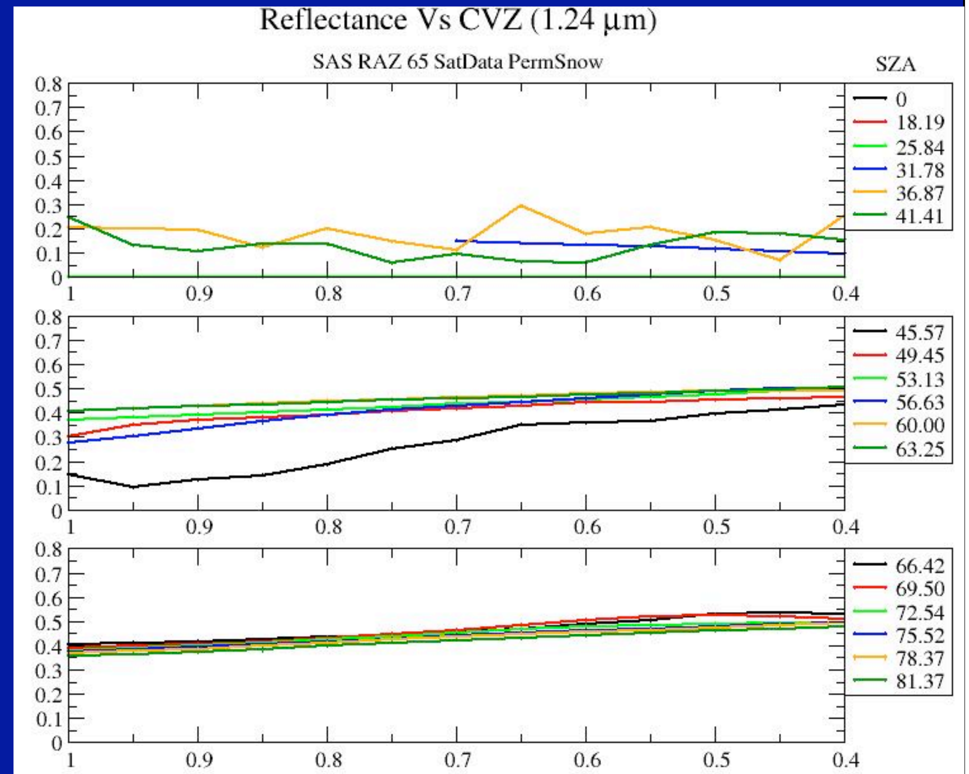
- Model" 750 μm/300 μm ice crystal, τ = 1000

Model



μ

Observations

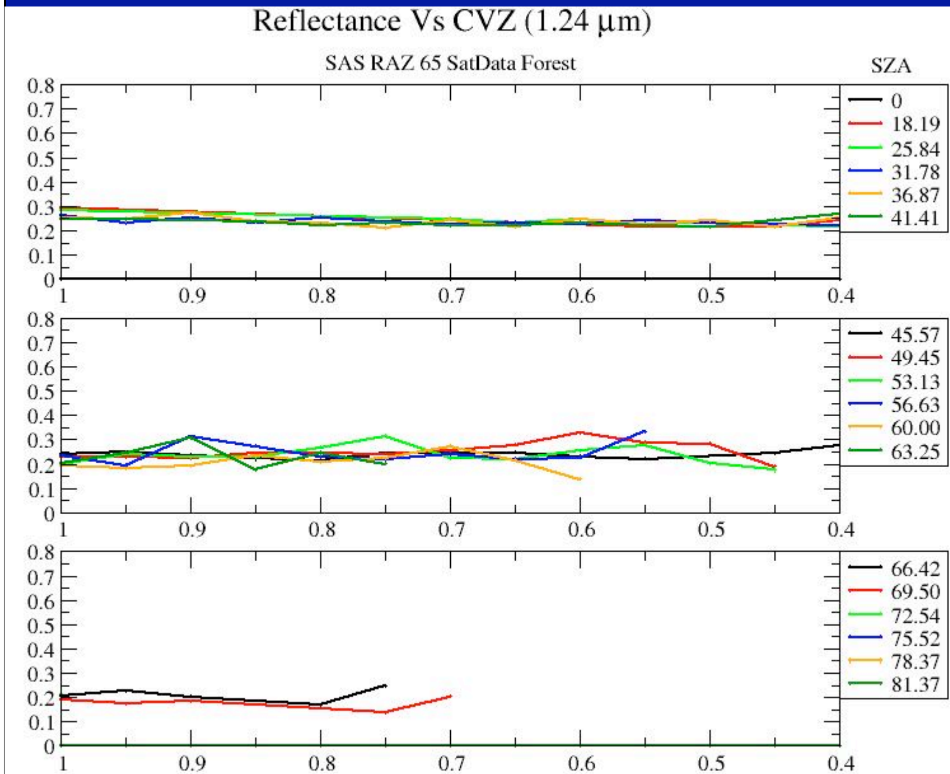


μ

- Good agreement for nadir view, model brighter at high angle views
  - *- no atmosphere in model*
  - *- particle size/shape probably not correct*

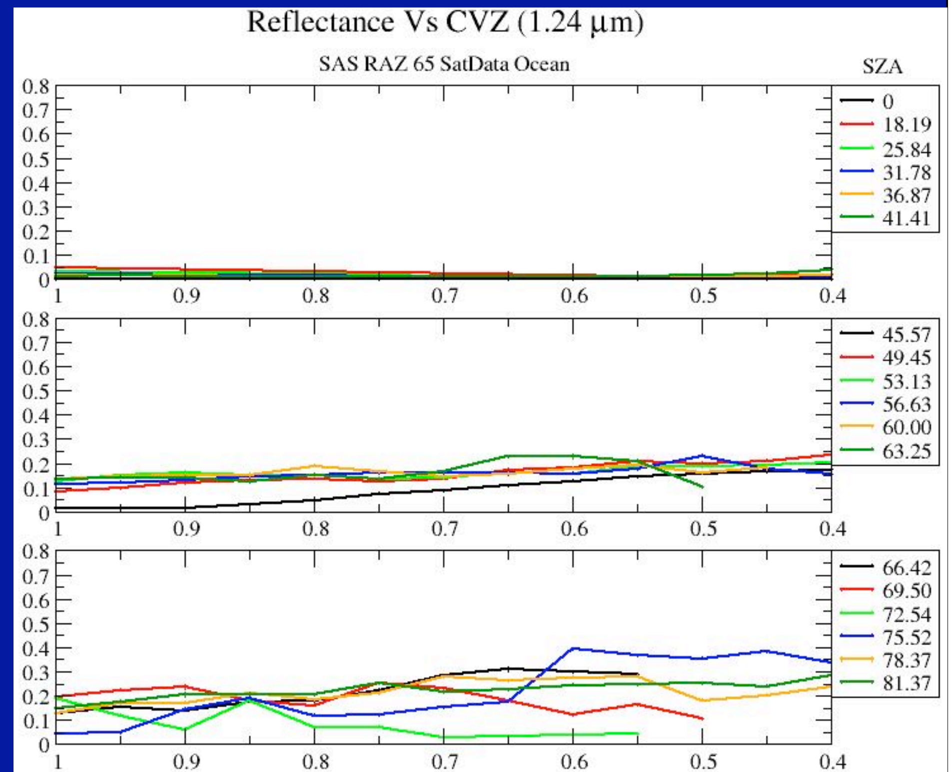
1.24-μm Clear Snow/Ice Reflectances Over Forest & Ocean Observed from Aqua MODIS, RAZ = 65°, Jan-Feb 2007

Forest



μ

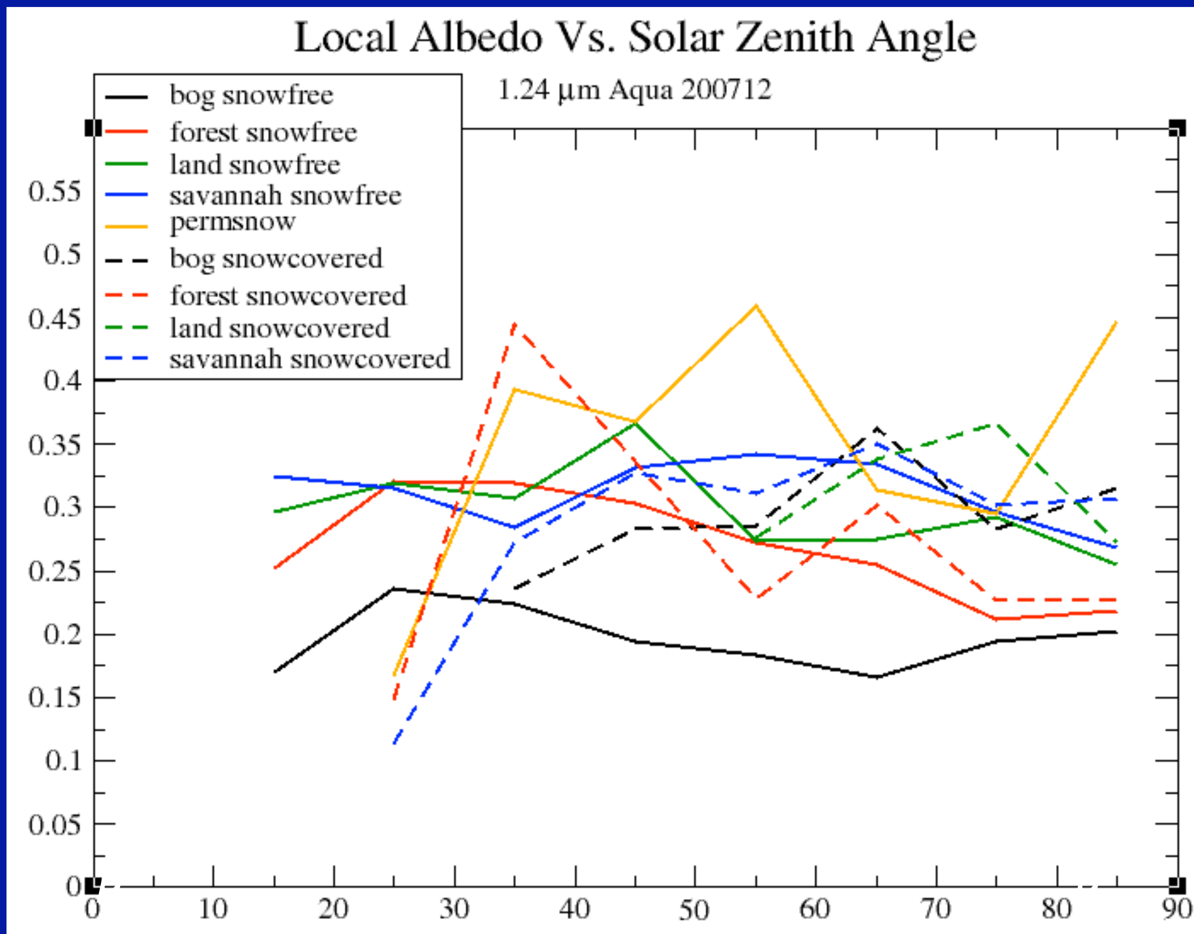
Ocean



μ

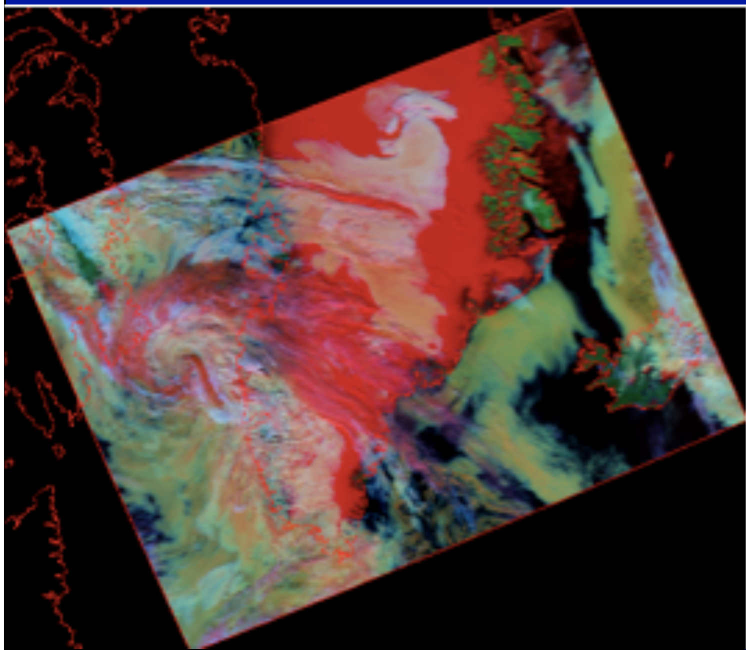
- Snow reflectances much smaller than for permanent snow
  - *forest shows little VZA or SZA dependence*
  - *ocean reflectances show increase w/ VZA, but dark*

1.24-μm Clear Albedos Over Various Land Types Observed from Aqua MODIS, December 2007

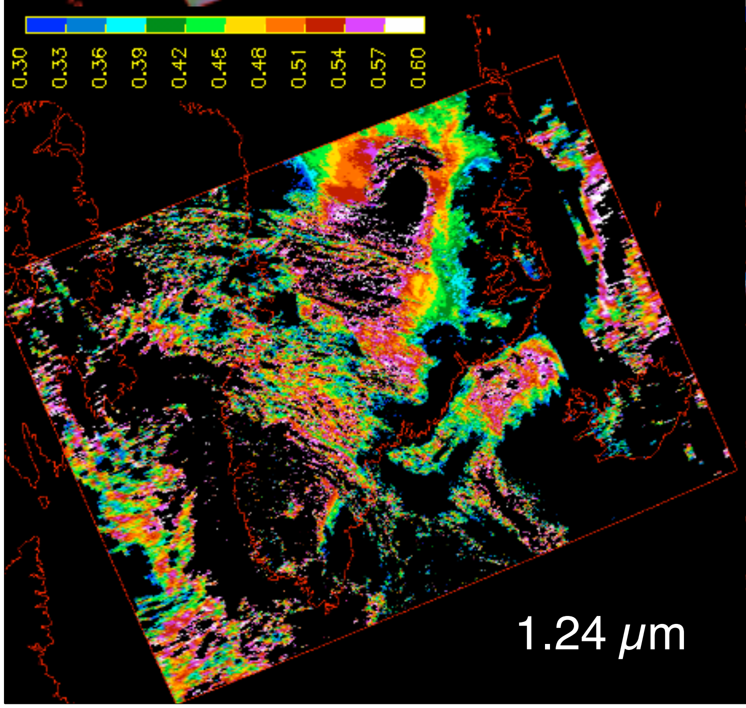


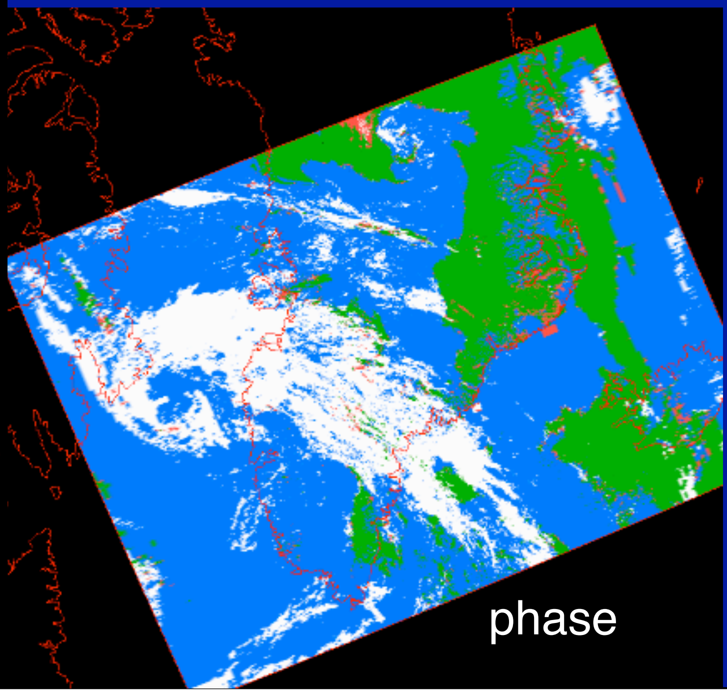
- Snow albedos not much different from snow-free albedos
  - *exception for bog areas*

1.24-μm Imagery Over Greenland



• Good contrast between snow and clouds over Greenland, cloud reflectances exceed 0.60 in many areas, while Greenland snow reflectance varies from < 0.30 to 0.48.





Retrieval Clouds over Snow Summary

- 2.13-*μ*m channel only good for small optical depth clouds

- Observations confirm 1.24-*μ*m channel as the best option

- Requires good estimates of background albedos
  - need both snow-covered & snow-free albedo maps
  - monthly dependent
  - maps need completion
    - *expect results by next week*

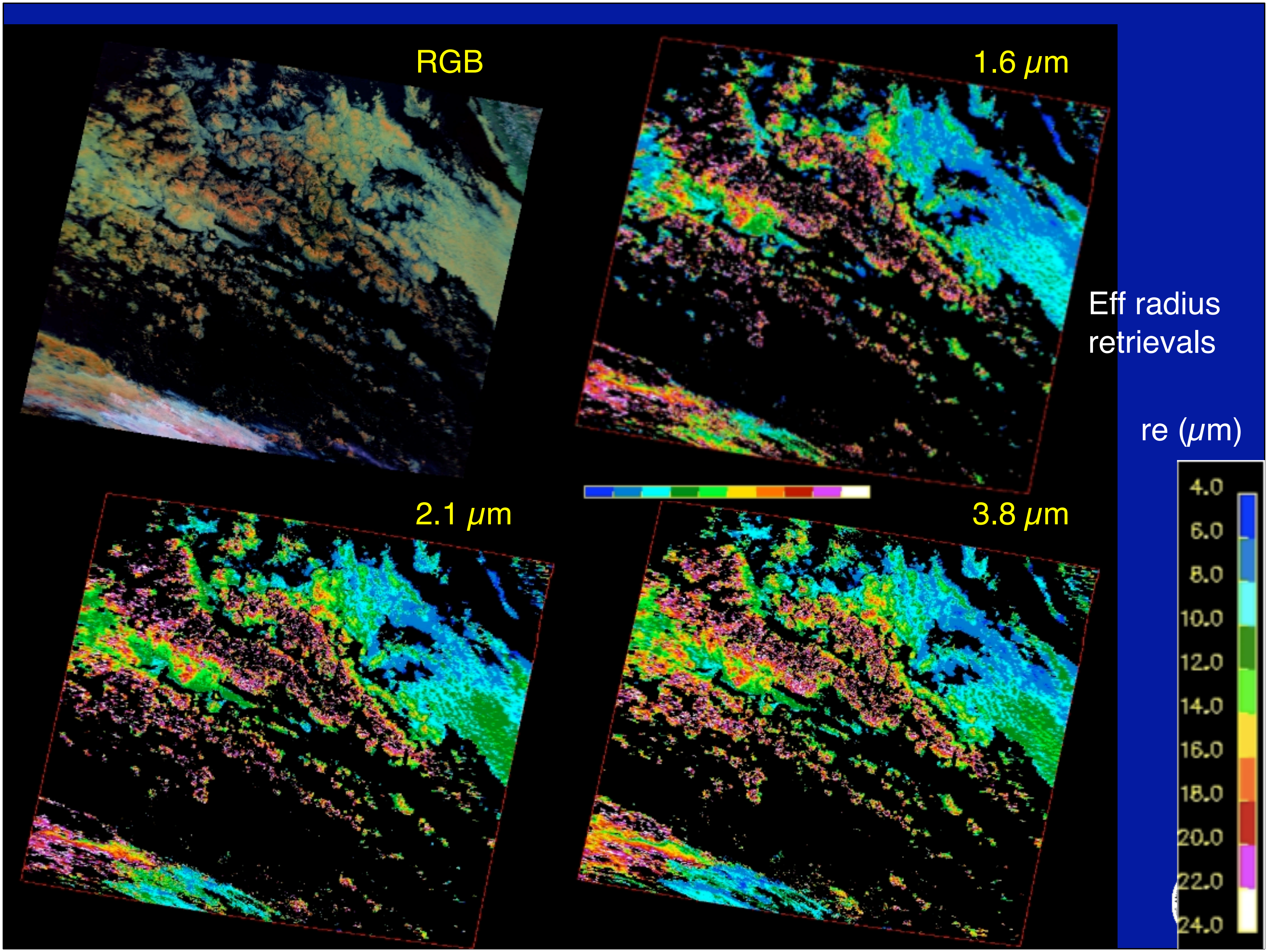
- Need to test implementation
  - complete retrieval code

- Examine potential of hybrid method (Ed4?)
  - small τ: 2.13, medium τ: 1.24 *μ*m; high τ: 0.64 *μ*m

Cloud Particle Size

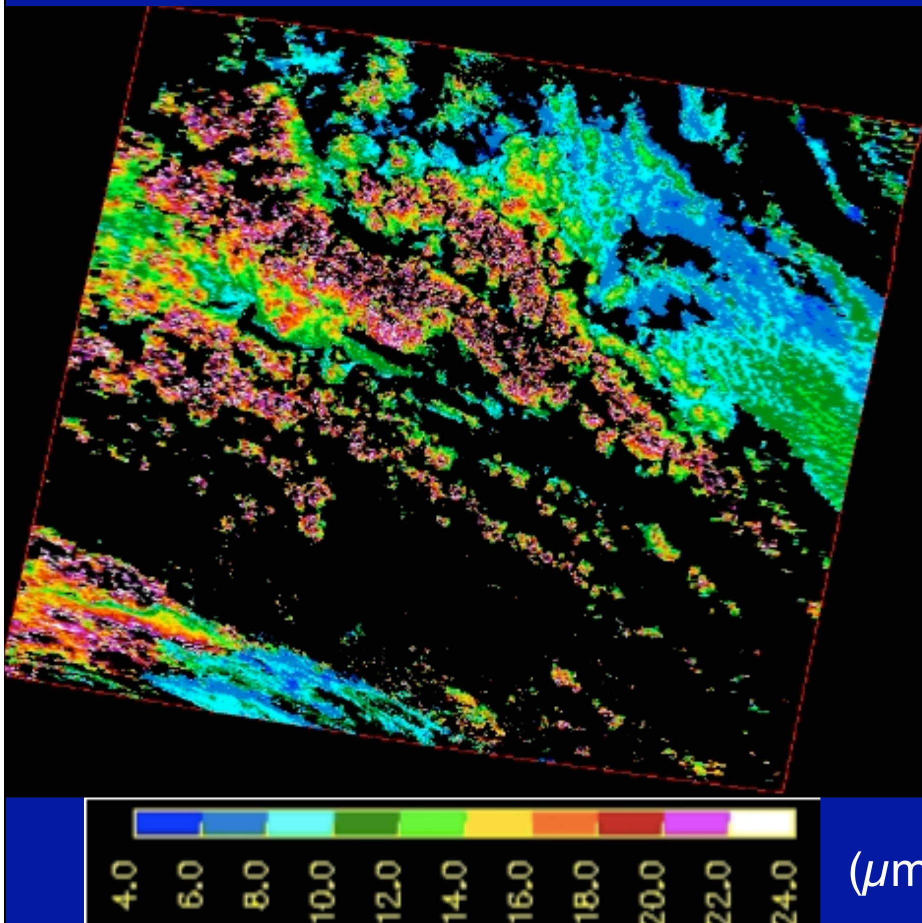
- new definition for particle size, $R_e = D_{eg}/2 = f(D_e)/2$
  - $R_e = (7.918*1.0E\text{-}9*D_e*D_e + 1.0013*1.0E\text{-}3*D_e + 0.4441)*D_e$

- 2.1-μm particle sizes being retrieved properly for water, but too large for ice
  - problem with saturated reflectance fields
  - recompute reflectance LUTs, solve starting with smallest re/Re, or make call to Chang's routine


RGB
1.6 μm
2.1 μm
3.8 μm
Eff radius
retrievals
re (μm)
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0

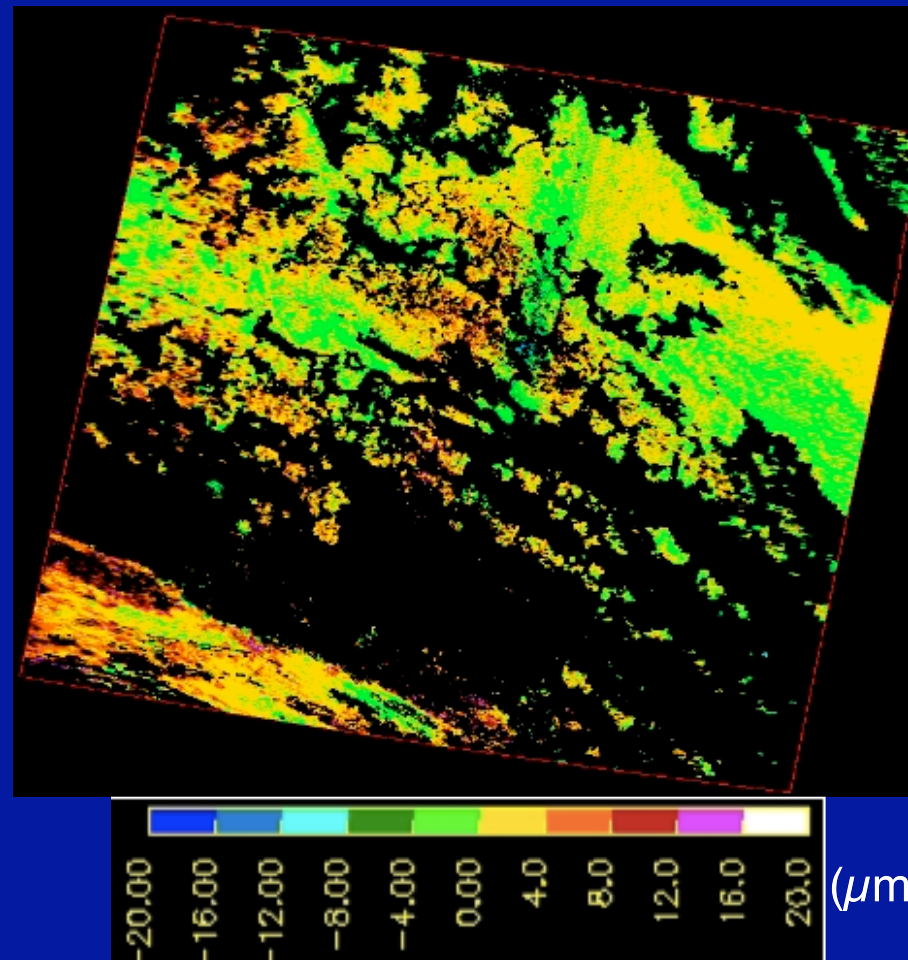
Multispectral effective radius retrievals

re(3.8)



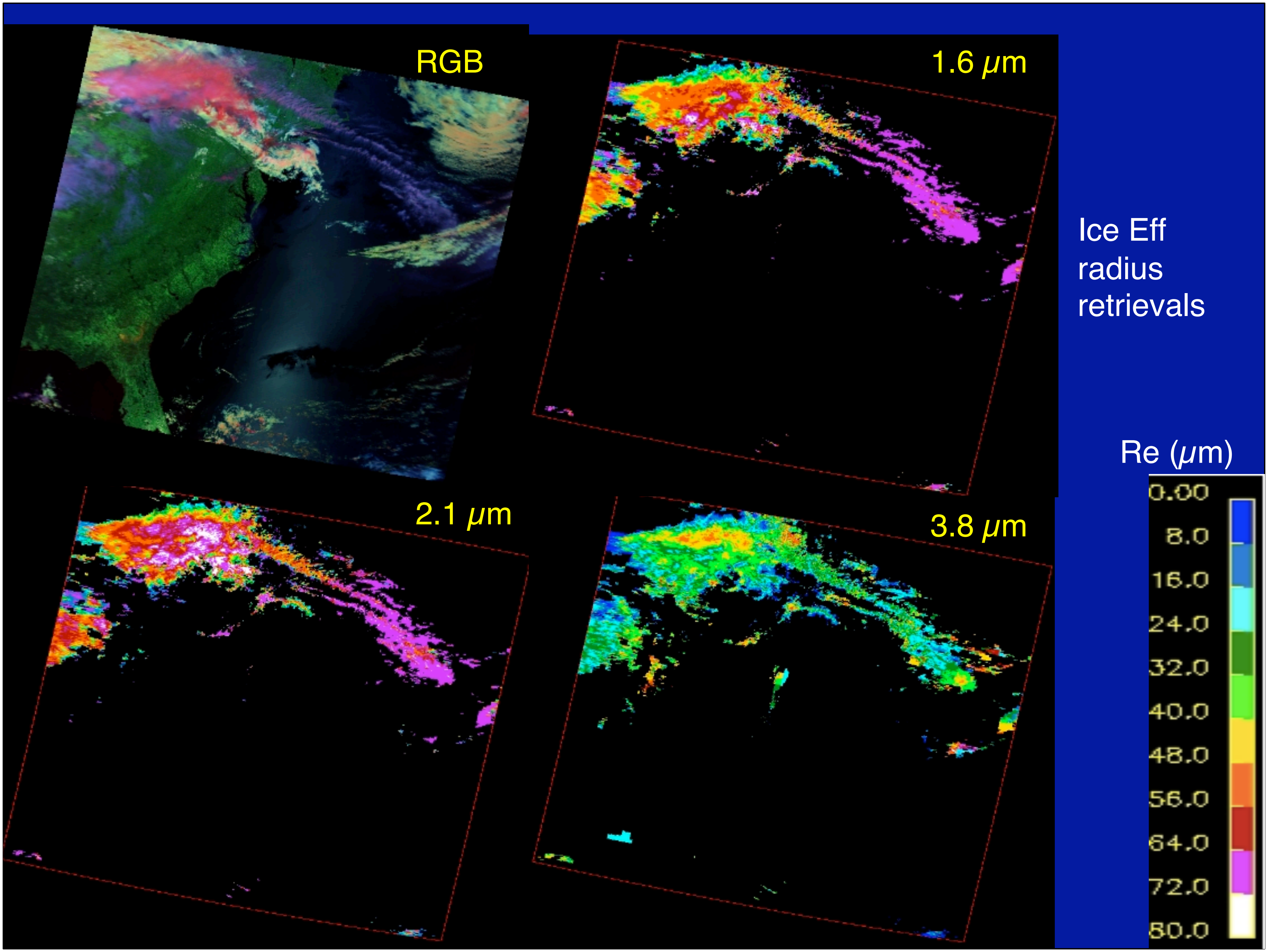
(μm)

re(2.1) - re(3.8)



(μm)

re(3.8) both larger and smaller than re(2.1), similar to MOD06 results

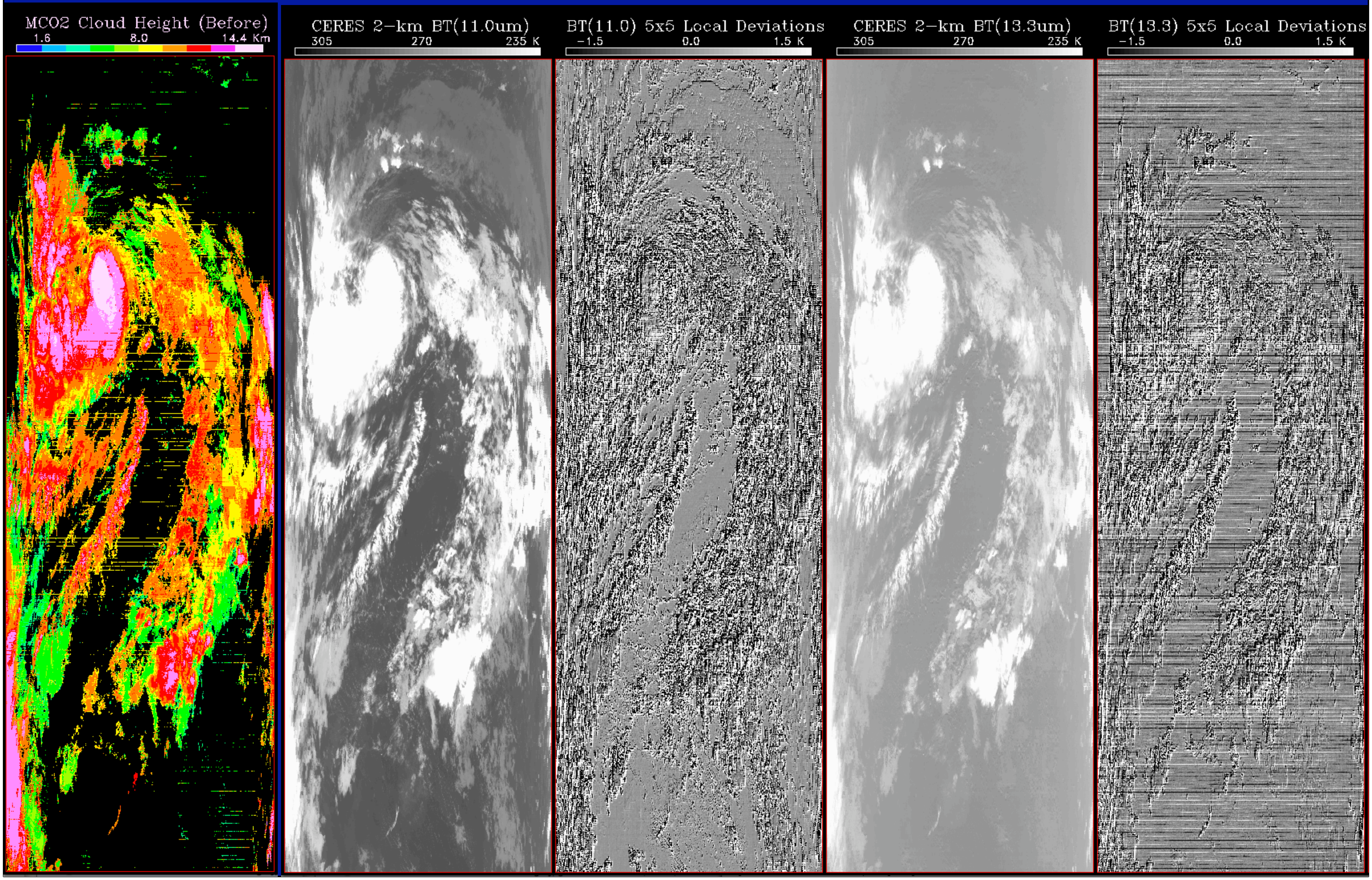

RGB
1.6 μm
Ice Eff
radius
retrievals
2.1 μm
3.8 μm
Re (μm)
0.00
8.0
16.0
24.0
32.0
40.0
48.0
56.0
64.0
72.0
80.0

Modified CO_2 Absorption Technique (MCO2) Cloud Heights

- Implemented de-striping algorithm for 13.3-μm channel
- MOA profiles & T_{cs} interpolated for each pixel
  - specific humidity used to recompute RH
  - eliminates blockiness in results
- Several bugs eliminated
- Recalculated humidity searched for maximum height level
  - full explanation in Chang talk

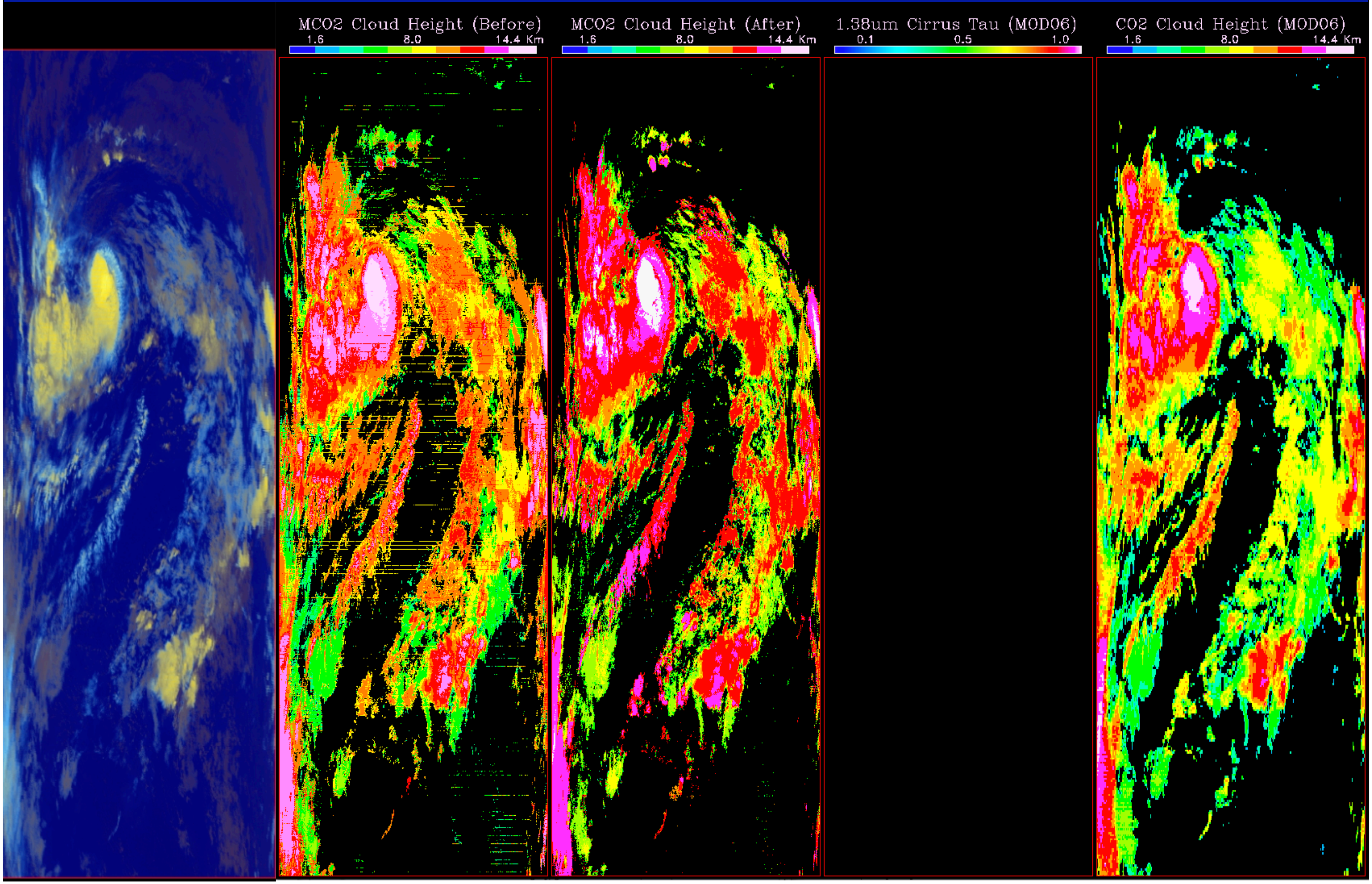
Illustration of Terra 13.3-µm detector striping problem

(Terra CERES 2-km granule: 2007/08/15, 0100)



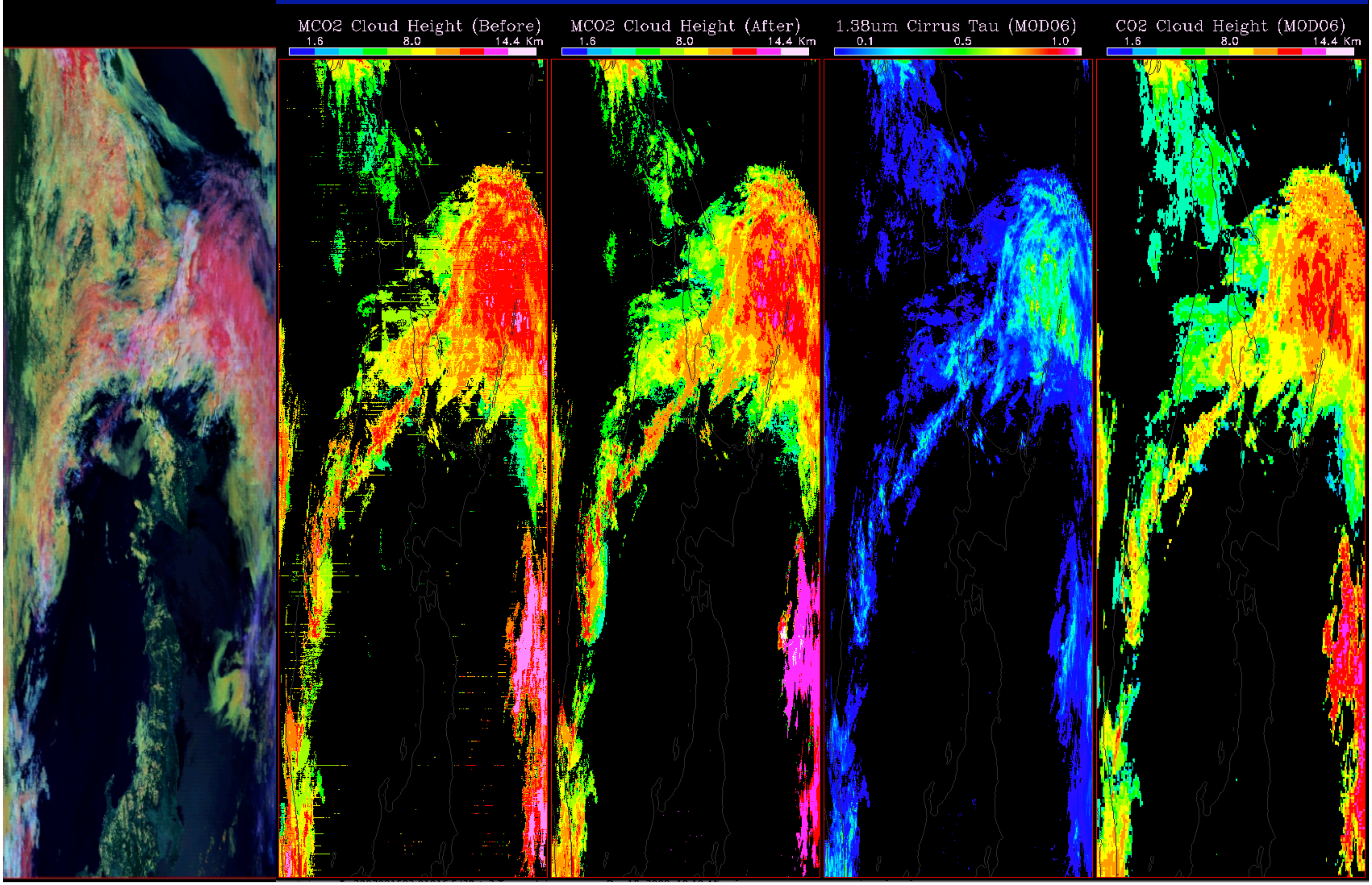
Reduction of Terra 13.3-µm detector striping problem

(Terra CERES 2-km granule: 2007/08/15, 0100)



Before-and-After Comparisons of MCO2 Cloud Height

(Terra CERES granule: 2007/08/15, 0135)



Before-and-After Comparisons of MCO2 Cloud Height

(Terra CERES granule: 2007/08/15, 0150)

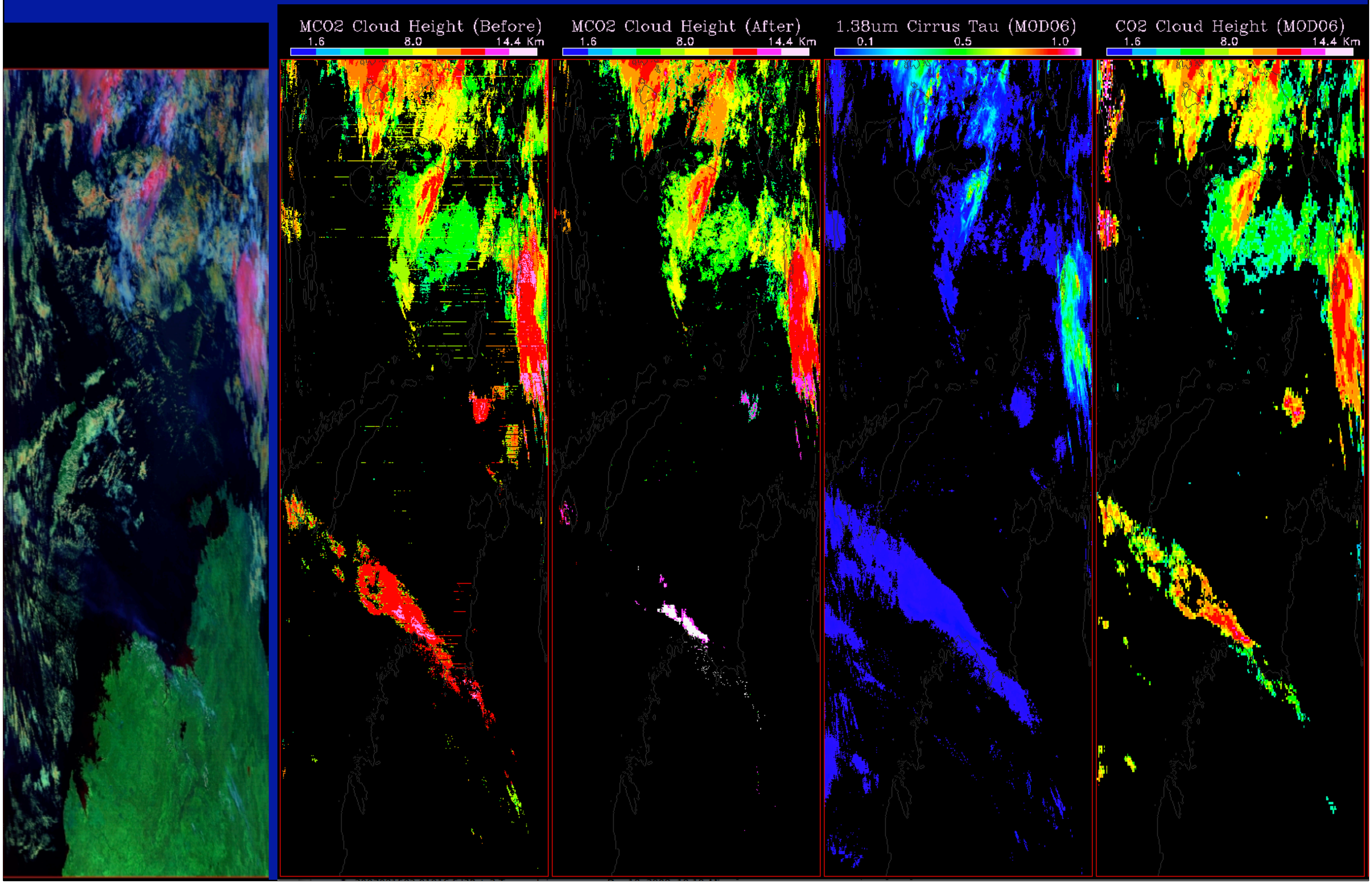
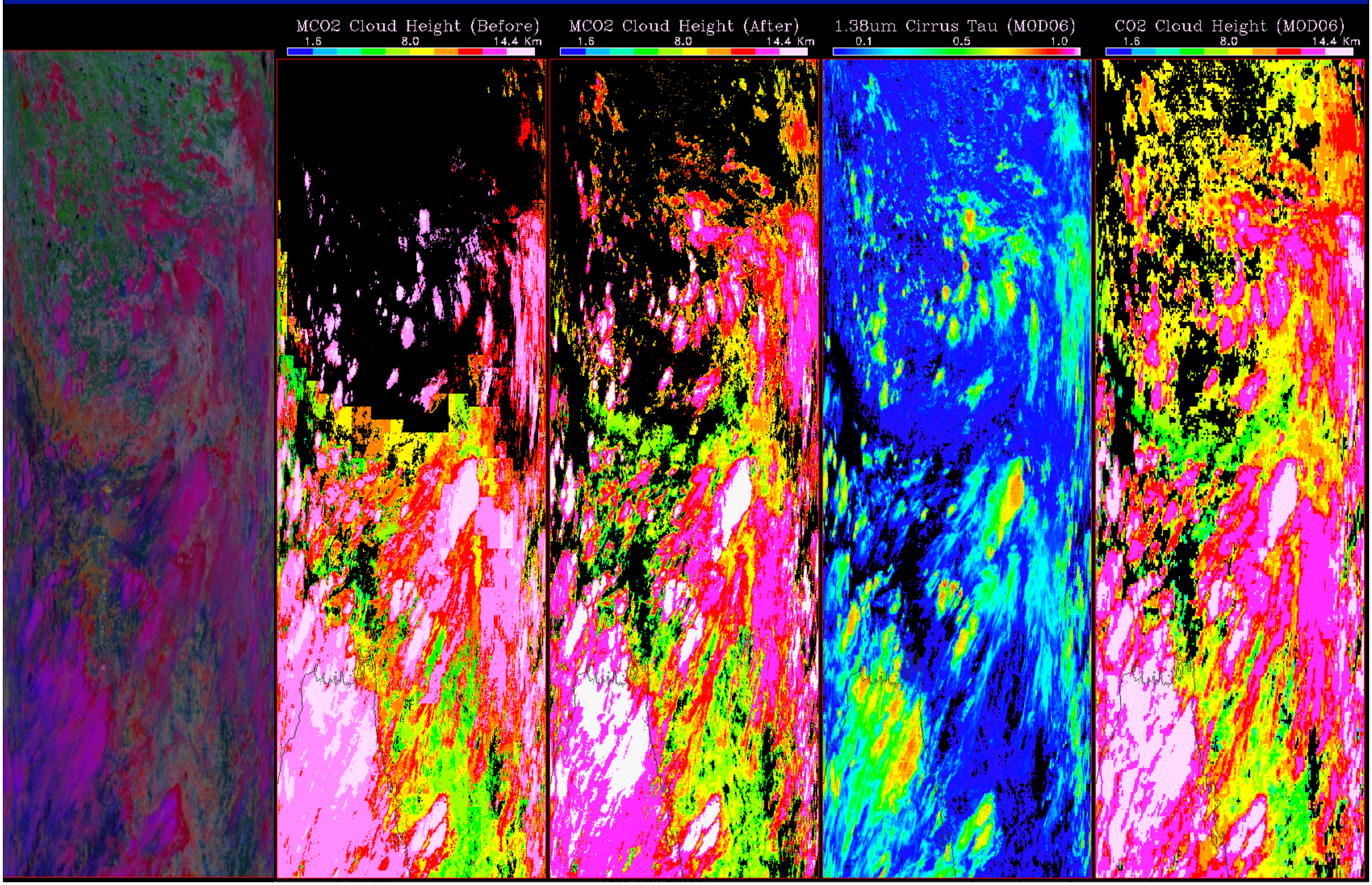
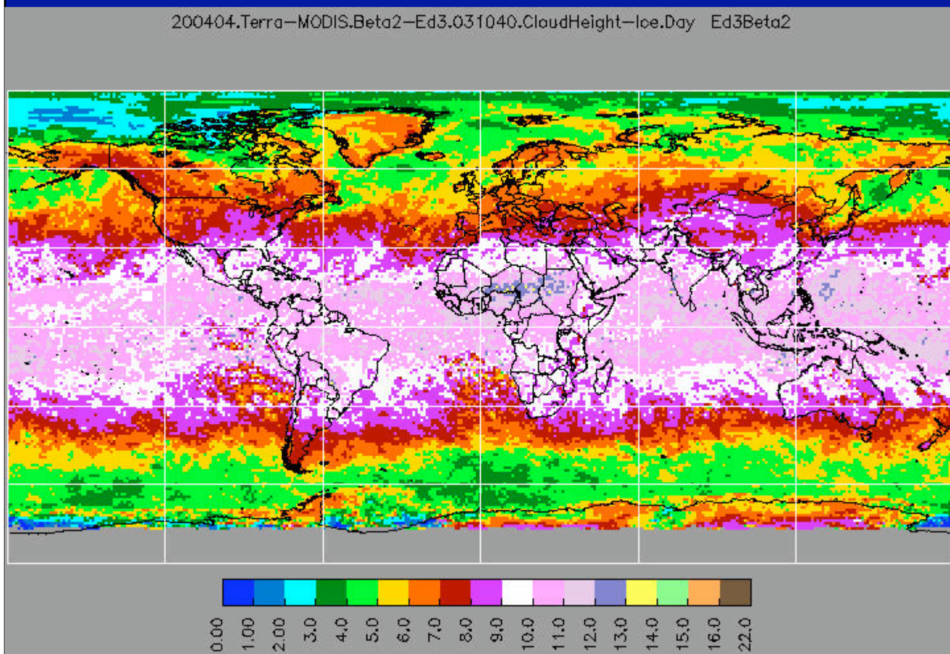


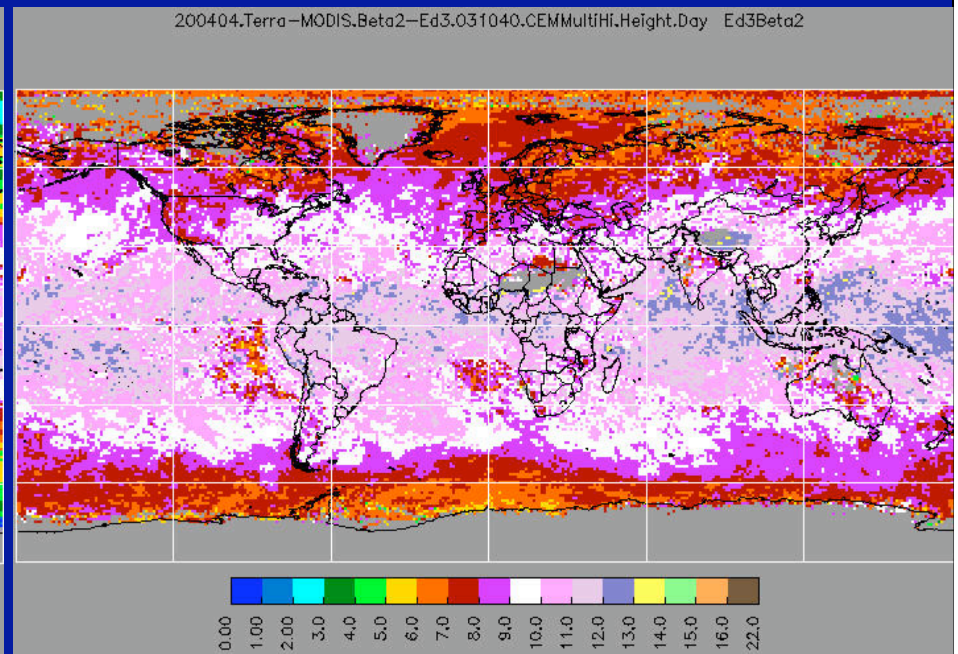
Illustration of Improved MCO2 Cloud Height over Tibet (high mountainous)

(Aqua CERES granule: 2004/07/15, 0705)



Multilayer vs Single-layer Ice Cloud Top Heights
Terra, April 2004





- Tropical clouds similar in height
- Mid-latitude & polar cloud tops much higher than for single-layer cases

MCO2 Cloud Height Summary

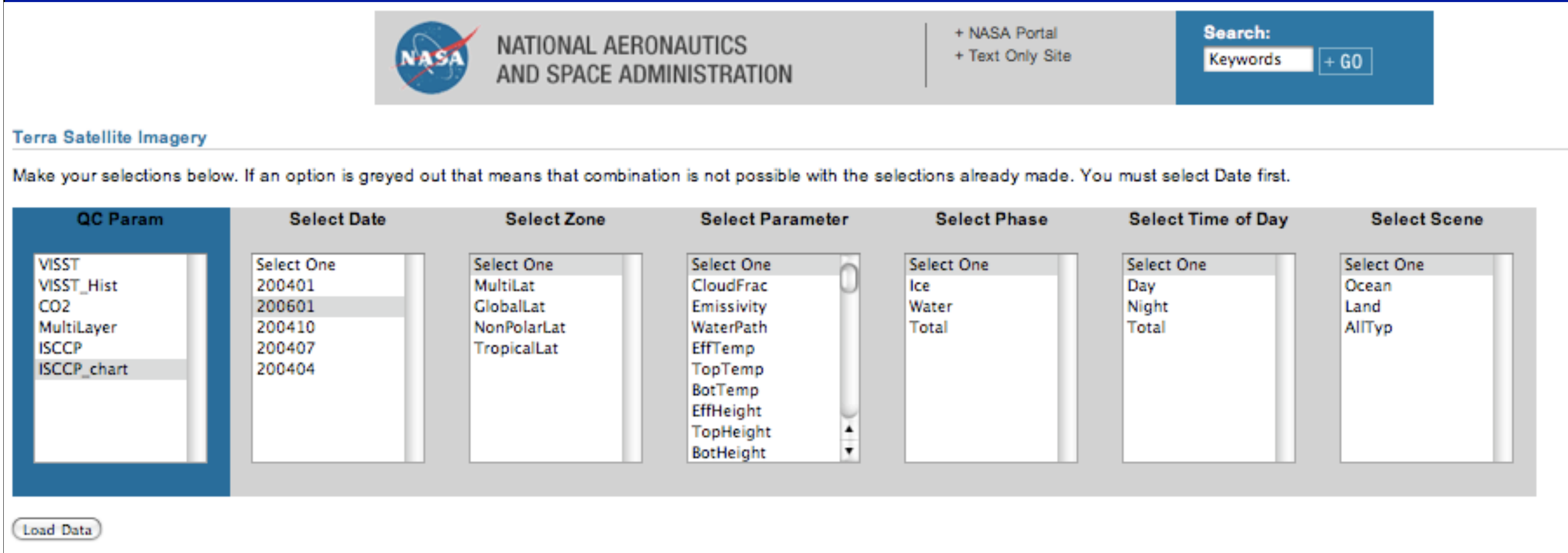
- De-striping algorithm eliminates striping in retrievals seen in Ed3-beta 2
  - striping occurs in all channels but cannot be eliminated in other channels except with full-res data
    - *if CERES ever gets a new data flow, request destriped data*
- MOA profiles & T_{cs} interpolated for each pixel
  - successfully eliminates blockiness in results
- Fewer high clouds found in new MCO2
- New heights tend to be higher than either old MCO2 or MOD06
  - what is source of difference, too high?

Ed3 Cloud Properties on SSF

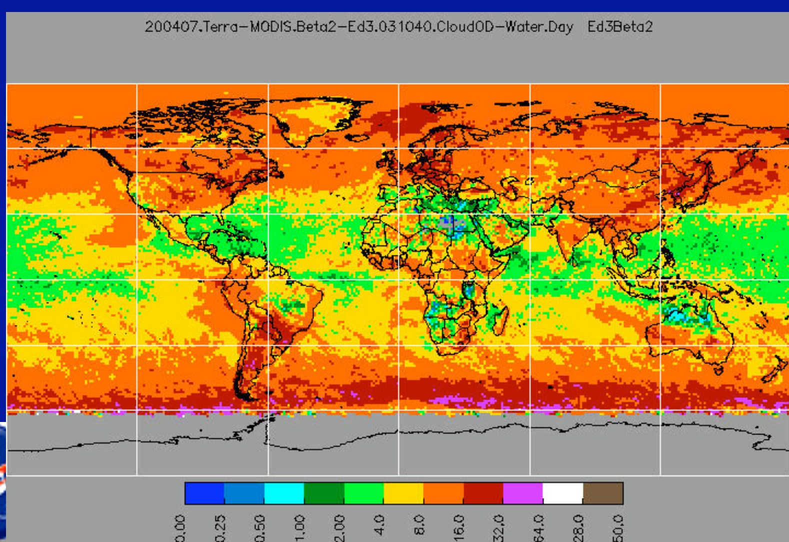
- All Ed2 parameters
- SSF-79, 79a: CWG Tskin, CWG PW
- SSF-94a, b: Cloud top temperature, height
- SSF 102a: Mean cloud base temperature
- SSF 108-110: re(1.6), Re(1.6), log[tau(1.6)]
- SSF 110a-c: re(2.1), Re(2.1), log[tau(2.1)]
- SSF 111: CO2 layer coverage
- SSF 111a-c: emissivity, pc, Tc for CO2
- SSF 112: CO2 Zc
- SSF 114a-l: multilayer, single-layer properties (n x 4)

  coverage, OD, log(OD), emissivity, pt, Tt, Zt
  Rere(3.7), re(3.7), Re(3.7)
  Rere(2.1), re(2.1), Re(2.1)

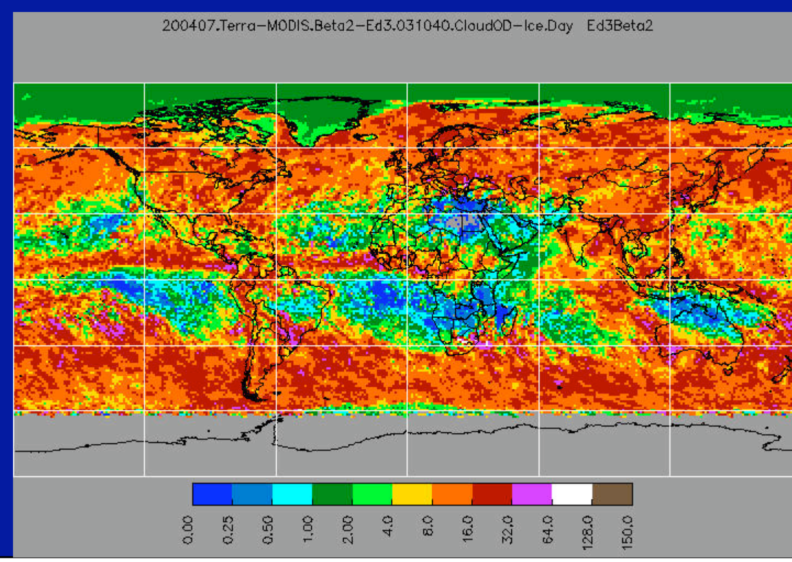
New Display Interface and Parameters



Water OD



Ice OD



Wrap-up Work for Final Ed3

- 0.64-μm Terra-Aqua differences: which is reference channel?
- Mask: test impact of 3.8 and 0.64-μm calibration changes
- Cloud phase
  - finalize nocturnal BSM/TSM algorithm & test
  - tweak daytime phase selection to properly detect altocumulus liquid
- Rough models? Final testing
- Using CO2: do not apply cloud-top height correction for thin cirrus?
- Cloud-top heights
  - test for potential ML clouds first to prevent overcorrecting
  - test seasonal lapse rates
- ML algorithm
  - use only two most certain categories? Decide when to perform retrieval
  - use only over non-snow sfcs?
- 2.13-μm saturation & models
  - test 1.24-μm channel retrievals over snow
  - test 2.1-μm ice cloud Re retrievals from Chang, reverse iteration, revised models

Bottom line: another month is highly desirable